

**JOURNAL**  
**OF THE**  
**AMERICAN SOCIETY**  
**OF AGRONOMY**

**VOLUME 30**

**1938**

**PUBLISHED BY THE SOCIETY**  
**GENEVA, N. Y.**



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JOURNAL  
OF THE  
**American Society of Agronomy**

VOL. 30

JANUARY, 1938

No. 1

**EFFECT OF APPLICATIONS OF FINE LIMESTONE: III.  
THE YIELD AND NITROGEN CONTENT OF  
INOCULATED AND NON-INOCULATED  
ALFALFA GROWN ON SHELBY LOAM<sup>1</sup>**

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THE effects of limestone on the growth and nodulation of legumes are varied and complex. It is thought by some investigators that the main function of calcium in plant growth is that of neutralizing the soil acidity, whereas others are of the opinion that the most important rôle played by calcium is that of a plant nutrient.

Many investigators (7, 8, 17, 19, 20, 22)<sup>3</sup> have reported beneficial effects due to liming and inoculation of legumes. Walker and Brown (21) obtained results showing that certain legume bacteria in the soil are favorably influenced by the application of limestone.

Albrecht and Davis (2) found that where small amounts of calcium were used soybeans were readily attacked by disease and only poor growth occurred, while with increased amounts of calcium, growth improved and seemed to be normal, but only as still greater amounts of calcium were available to the plant would nodulation occur. Allison and Ludwig (4) suggested that nodule formation will not occur unless there is present a rapid growth of root tissue and that factors retarding rapid root growth also retard nodulation. Truog (18) observed that roots of alfalfa plants grown in acid soils may not be infected even though there are present large numbers of the desired legume bacteria in the soil.

Nodulation and plant growth of legumes have been studied by various investigators when a part of the roots were grown in acid soils and a part in limed soils. Karraker (10) noted that the effect of soil reaction on alfalfa is localized and affects only that part of the roots directly in contact with the acid soil. Albrecht and Davis (3) and Doolas (6) obtained similar results by growing soybeans in the greenhouse with the roots extending partially through acid zones of soil ranging in

<sup>1</sup>Journal Paper No. J489 of the Iowa Agricultural Experiment Station, Ames, Iowa. Project No. 405. Received for publication August 30, 1937.

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<sup>3</sup>Figures in parenthesis refer to "Literature Cited", p. 8.

pH from 3.8 to 5.6. Distinct differences in the plant cell wall structure of soybean seedlings were noted in the micro-sections made of calcium-starved seedlings and those grown on soil containing calcium.

Upon adding calcium acetate to Gray silt loam and Bates fine sandy loam, both acid soils, Scanlan (15) secured very little change in acidity, but the nodulation of soybeans increased 1,000%. In a similar experiment on Putnam silt loam nodulation was increased 433%.

From a series of experiments, Sewell and Gainey (16) concluded that the reaction of the soil, if within a range of pH 4.5 to 7.0, is a minor factor in the growth of alfalfa, providing all of the needed nutrients are supplied.

According to Crist and Weaver (5), nutrients, when available, are taken from the deeper soil layers in large quantities which may produce pronounced effects upon the quantity and quality of the crop yield.

Previous investigations (1, 11, 12, 13, 14) have shown quite clearly that some legumes may be satisfactorily grown on acid soils where small amounts of fine limestone are applied in the row with the seed. Since this method is practiced, it would be of value to know whether legumes grown in this manner fix as much nitrogen as those grown in fully neutralized soils. This experiment was designed and a greenhouse and laboratory study made of the effects of fine limestone in the row and beside the row on the nitrogen content of inoculated and non-inoculated alfalfa plants grown on Shelby loam.

## EXPERIMENTAL

The surface soil of a Shelby loam, having a pH of 5.40, a lime requirement (9) of 3.0 tons per acre, and a total nitrogen content of 3,270 pounds per acre, was employed in this experiment. The fine limestone used, which passed a 100-mesh sieve, was 95.5%  $\text{CaCO}_3$ .

The soil was air dried and screened through a  $\frac{3}{4}$  inch sieve. Thirty-four pounds of air-dry soil were placed into each of 24 4-gallon earthenware pots. The treatments were made in triplicate and a 20% superphosphate was applied broadcast to the upper 7 inches of soil in all of the pots. The soils receiving 6,015 pounds of fine limestone per acre applied broadcast were also treated at this time. Two weeks elapsed from the time of potting the soil to the time of planting. Alfalfa was seeded in two rows, 5 inches apart and 10 inches long across each pot. The pots were arranged in the greenhouse according to a randomization procedure and the pots were re-randomized once every two weeks throughout the experiment. Artificial lights were employed about 8 hours each day throughout the winter months.

The method of applying fine limestone beside the row was to apply one-half of the desired amount  $\frac{1}{2}$  inch on each side of the row at the same depth as the seed. All seeds were sown  $\frac{2}{3}$  inch deep and the growth in all pots thinned down to 12 plants per pot.

An outline of the treatment is given in Table 1.

A stock culture of an efficient strain of *Rhizobium meliloti* was used to inoculate the alfalfa used in the inoculated series. The seeds were inoculated at the time of seeding and dusted with a mercury dust. One hundred twenty days after planting, the tops and roots of the plants were harvested separately, dried, weighed, ground, and analyzed for total nitrogen by the Kjeldahl method. The data secured were analyzed statistically according to the method of analysis of variance.

TABLE 1.—Outline of treatments.

Treatment per acre	Inoculated pot No.	Non- inoculated pot No.
None.....	A-B-C	A-B-C
500 pounds fine limestone applied in row.....	A-B-C	A-B-C
500 pounds fine limestone applied beside the row....	A-B-C	A-B-C
6,015 pounds fine limestone applied broadcast.....	A-B-C	A-B-C

## RESULTS

In the inoculated series it was noticed at the time of harvest that about 85% of the roots of the plants grown on the untreated soils were inoculated, whereas in the non-inoculated series about 25% of the plants were inoculated. The roots of the plants grown on the soils receiving limestone were 100% inoculated in the inoculated series. The plants grown on the fully limed soils in the inoculated series contained many more nodules than those grown on the other treated soils. In the non-inoculated series about 17% of the plants were inoculated where limestone was applied beside the row, 40% where limestone was applied in the row, while approximately 55% of the plants grown on the fully limed soils were inoculated. In all cases only very few nodules per plant were found on those plants which were inoculated in the non-inoculated series. The fact that a great many of the plants in the non-inoculated series were inoculated must be taken into consideration in evaluating the results of this experiment.

No nodules were observed on the tap roots of any of the plants. This may have been due to the mercury dust used to control the "damping-off" organism. The use of this mercury dust might also account for the small difference between the weights of the inoculated and non-inoculated plants. In the inoculated series a concentration of nodules on the root hairs was observed in the limed zone where the fine limestone was applied in the row.

The pH determinations of the soil at the time of harvest are given in Table 2. The results in this experiment were similar to those obtained in the previous experiments (11, 12) in that it was found that the limestone applied in the row did not neutralize the second inch of soil to any appreciable extent.

## YIELD AND NITROGEN CONTENT OF INOCULATED AND NON-INOCULATED ALFALFA

The yield and nitrogen content of the inoculated and non-inoculated alfalfa are shown in Table 3. An analysis of variance was also made on the yield and nitrogen content of the plants and the results are given in Table 4.

The analysis of variance of the total dry weight and total nitrogen content showed a highly significant difference between the inoculated and non-inoculated alfalfa. The inoculated plants weighed more and contained more nitrogen than the uninoculated plants. A highly significant difference was found to exist between the total dry weight and total nitrogen content of alfalfa grown on soil receiving limestone in

TABLE 2.—*The pH of soils at the time of harvesting inoculated and non-inoculated alfalfa grown on Shelby loam.\**

Region of sampling	Block	Inoculated, pH	Non- inoculated, pH
No Treatment			
In the row 0 to 1 in. deep. ....	A	5.46	5.50
	B	5.49	5.45
	C	5.50	5.50
Mean. ....		5.48	5.49
In the row 1 to 2 in. deep. ....	A	5.49	5.46
	B	5.48	5.45
	C	5.46	5.48
Mean. ....		5.48	5.47
500 lbs. Fine Limestone in the Row			
In the row 0 to 1 in. deep. ....	A	6.73	6.84
	B	6.74	6.76
	C	6.81	6.86
Mean. ....		6.76	6.82
In the row 1 to 2 in. deep. ....	A	5.51	5.59
	B	5.54	5.56
	C	5.51	5.57
Mean. ....		5.52	5.57
500 lbs. Fine Limestone Beside the Row			
In the row 0 to 1 in. deep. ....	A	6.52	6.42
	B	6.57	6.36
	C	6.63	6.39
Mean. ....		6.57	6.39
In the row 1 to 2 in. deep. ....	A	5.56	5.58
	B	5.54	5.48
	C	5.50	5.54
Mean. ....		5.54	5.53
6,015 lbs. Fine Limestone Applied Broadcast			
In the row 0 to 1 in. deep	A	7.26	7.35
	B	7.30	7.43
	C	7.40	7.45
Mean. ....		7.32	7.41
In the row 1 to 2 in. deep. ....	A	7.28	7.38
	B	7.41	7.38
	C	7.45	7.48
Mean. ....		7.38	7.41

\*The pH determination of soil at beginning of experiment was 5.40.

the row in comparison with the alfalfa grown on the untreated soil. No significant difference was found in the total dry weight or total

TABLE 3.—The yield and nitrogen content of inoculated and non-inoculated alfalfa grown on Shelby loam.

Inoculated										Non-inoculated					
Tops			Roots			Total plant		Tops			Roots			Total plant	
Yield, lbs.	N, %	Total, mgms	Dry weight, grams	N, %	Total, mgms	Total weight, grams	Total, mgms	Dry weight, grams	N, %	Total, mgms	Dry weight, grams	N, %	Total, mgms	Total weight, grams	Total, mgms
No Treatment															
8.0	3.02	251.6	5.8	1.81	105.6	13.8	347.2	7.4	3.07	227.2	4.0	1.73	69.6	11.4	296.8
8.3	3.01	250.7	5.3	1.85	98.6	13.3	349.3	7.0	2.91	204.4	4.8	1.64	79.2	11.8	283.6
8.5	3.05	259.3	5.6	1.74	98.0	14.1	357.3	7.5	2.95	221.3	4.0	1.87	74.8	11.5	296.1
8.3	3.03	250.5	5.6	1.81	100.7	13.7	351.3	7.3	2.98	217.6	4.3	1.75	74.5	11.6	292.2
500 lbs. Fine Limestone in Row															
8.4	3.35	281.4	7.0	1.93	135.8	15.4	417.2	7.6	3.53	268.3	6.0	2.02	121.2	13.6	389.5
10.4	3.32	345.3	6.5	2.01	130.7	16.9	476.0	8.0	3.44	276.0	6.3	1.84	116.6	14.3	392.6
9.5	3.43	326.8	6.4	2.12	135.7	15.9	462.5	8.3	3.56	296.3	5.3	2.14	113.4	13.6	409.7
9.4	3.33	317.8	6.5	2.02	134.0	16.1	451.9	8.0	3.52	280.2	5.9	2.00	117.0	13.8	397.3
500 lbs. Fine Limestone Beside Row															
8.5	3.41	289.9	5.1	2.03	103.5	13.6	393.4	8.1	3.25	263.3	7.4	1.87	138.4	15.5	401.7
8.0	3.41	273.6	6.1	1.98	120.8	14.1	394.4	8.4	3.26	274.7	6.5	2.05	133.9	14.9	408.6
8.6	3.56	306.2	6.1	2.19	134.8	14.7	440.4	7.1	3.17	225.8	6.4	1.93	124.2	13.5	350.0
8.4	3.43	289.9	5.7	2.07	119.5	14.5	409.4	7.9	3.23	254.6	6.8	1.95	132.1	14.6	386.8
6,015 lbs. Fine Limestone Applied Broadcast															
10.0	3.62	362.0	6.0	2.34	141.0	16.0	503.0	8.0	3.41	272.8	6.0	2.26	136.2	14.0	409.0
10.5	3.68	387.5	6.1	2.34	143.4	16.6	530.9	10.5	3.51	369.6	5.1	2.26	115.3	15.6	484.9
11.5	3.52	404.8	6.8	2.27	155.0	18.3	559.8	8.3	3.53	295.5	7.5	2.12	159.8	15.8	455.3
10.7	3.61	384.7	6.3	2.33	146.4	16.9	531.2	8.9	3.49	312.6	6.2	2.22	137.1	15.1	449.7

weight (5% moisture).

TABLE 4.—*Analysis of variance of the dry weight and nitrogen content of inoculated and non-inoculated alfalfa grown on Shelby loam.*

Source of variation	Degrees of freedom	Mean square					
		Tops		Roots		Total plant	
		Dry weight	Total N	Dry weight	Total N	Dry weight	Total N
Between blocks .....	2	.80	961.7	.06	110.12	.71	117.82
Between inoculation .....	1	8.16†	13,532.7†	3.78†	597.00	12.32†	17,779.7†
Between treatment .....							
L <sub>r</sub> -L <sub>s</sub> .....	1	1.02	2,148.0	.083	.23	.96	2,106.75
2L <sub>f</sub> -L <sub>r</sub> -L <sub>s</sub> .....	1	7.74†	13,026.4†	.027	134.69	7.65†	25,058.89†
3L <sub>o</sub> -L <sub>r</sub> -L <sub>s</sub> -L <sub>f</sub> .....	1	5.33†	22,411.9†	8.06†	8,486.87†	27.62†	60,552.0†
Inoculation X treatment .....	3	.56	900.7	.38	412.81	2.54*	882.83
Error .....	14	.473	791.8	.404	177.99	.570	721.37
Total .....	23	1.39	2,905.67	.820	572.58	2.85	5,152.2
L <sub>s</sub> -L <sub>o</sub> .....	1	.333	17,495.60†	—	—	9.01†	4,370.08*
L <sub>r</sub> -L <sub>o</sub> .....	1	2.52*	31,744.65†	—	—	15.87†	12,649.01†

\*Significant.

†Highly significant.

L<sub>o</sub> = No treatment.L<sub>r</sub> = 500 pounds fine limestone in the row.L<sub>s</sub> = 500 pounds fine limestone beside the row.L<sub>f</sub> = 6.015 pounds fine limestone applied broadcast.

nitrogen content of the plants grown on soils receiving limestone in the row and those on soils receiving limestone beside the row. The plants grown on soils treated with limestone, regardless of the method of application, were highly significantly larger and contained more nitrogen than the plants grown on the unlimed soils. The analysis further shows that the total dry weight and total nitrogen content of the plants grown on fully limed soils were highly significantly greater than in the case of the plants grown on the soils receiving limestone in the row or beside the row. With the roots alone, however, the difference was not significant. The relatively small interaction mean square (inoculation  $\times$  treatment) indicates that the nitrogen content of the alfalfa grown on the variously limed soils varied similarly irrespective of degree of inoculation.

#### THE INOCULATED SERIES

There was very little difference between the dry weight of alfalfa grown on the untreated soils and that on soil receiving limestone applied beside the row in the inoculated series. The dry weight of the plants grown on the soil receiving limestone in the row was somewhat greater than that of the plants on the soils receiving limestone beside the row. The fully limed soils supported the greatest plant growth and the plants had the largest percentage nitrogen of all the plants grown.

The largest root growth was secured where limestone was applied in the row, however the dry weight of the roots of the plants grown on the fully limed soil was almost as great. The percentage nitrogen and total nitrogen content of the roots of the plants on the fully limed soils were larger than in the case of the plants on any of the other soils. The nitrogen content of the roots of the plants grown on the soils receiving limestone in the row approached that of the roots of the plants grown on fully limed soils.

The smallest crop with the lowest content of nitrogen was obtained on the untreated soils. The total dry weight and total nitrogen content of the plants grown on the soils receiving limestone beside the row were lower than in the case of the plants grown on soils receiving limestone applied in the row. The total dry weight and total nitrogen content of the plants grown on fully limed soil were greater than under any of the other treatments. In the case of the plants grown on the soils receiving limestone in the row, the yield and nitrogen content approached the figures for the plants grown on the fully limed soils. This was especially true for the total dry weight. The total dry weight and total nitrogen content of the plants were less where limestone was applied beside the row than when it was applied in the row.

#### NON-INOCULATED SERIES

The same general relationship between treatments and the dry weight and nitrogen content of the plants was observed in the case of the non-inoculated and inoculated plants; however, the differences were not as great in the non-inoculated series as in the inoculated series.



Comparing the non-inoculated series with the inoculated series, it is evident that the non-inoculated plants as a whole gave smaller crop yields and contained less nitrogen than the inoculated plants. These differences were highly significant.

#### SUMMARY AND CONCLUSIONS

An investigation was made on Shelby loam to study the effects of fine limestone applications in the row and beside the row on the yield and nitrogen content of inoculated and non-inoculated alfalfa plants. The plants were harvested at the stage of inflorescence, oven-dried, and analyzed for total nitrogen by the Kjeldahl method. The data obtained were analyzed statistically according to the method of analysis of variance and the results are summarized as follows:

1. A mercury dust used to control the "damping-off" organism probably prevented a thorough inoculation of the alfalfa grown in the inoculated series on Shelby loam.
2. In the inoculated series a concentration of nodules was observed in the limed zone where the fine limestone was applied in the row.
3. The total dry weight and total nitrogen content of the plants grown on fully limed soils were highly significantly greater than in the case of the plants grown on soils receiving limestone in the row or beside the row.
4. The total dry weight and total nitrogen content of alfalfa grown on the untreated soils was highly significantly less than those secured on the soils receiving limestone.
5. The nitrogen content of alfalfa grown on the variously limed soils varied similarly, irrespective of the degree of inoculation.
6. The total dry weight and total nitrogen content of alfalfa grown in the inoculated series on Shelby loam was highly significantly greater than those plants grown in the non-inoculated series.
7. The yield of alfalfa grown on the soil receiving 500 pounds of fine limestone in the row appeared to be nearly as great as that secured from the fully limed soil; however, the total nitrogen content of the plants was much less. Apparently the partial liming of Shelby loam is quite favorable for the growth of alfalfa but only as the full lime requirement of a soil is reached will maximum nitrogen fixation be obtained.

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## THE STATISTICAL ANALYSIS OF A SPACING EXPERIMENT WITH SWEET CORN<sup>1</sup>

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**D**URING the past 15 years a variety of sweet corn, USDA-34, has been developed at the Puerto Rico Experiment Station of the U. S. Dept. of Agriculture, Mayaguez, Puerto Rico, and in a number of field trials has shown itself to be well adapted to the environmental conditions of the tropics.

Trial shipments of this variety of sweet corn have shown that good prices may be obtained when it is marketed in New York in the winter months. It was apparent, however, that there was a dearth of knowledge of the most efficient agronomic methods to use in the production of this sweet corn for market. Yields of nonmarketable ears and of forage also may be an important consideration for the grower operating a small enterprise typical of the Puerto Rican farm where a large return per acre per month is required to support the heavy population.

Accordingly, an experiment was designed to determine the relationship between soil area per plant and yield with USDA-34 sweet corn.

### METHODS AND EXPERIMENTAL DESIGN

There were six spacing treatments in the experimental design. These varied by  $\frac{1}{2}$ -square-foot intervals from 2.0 to 4.5 square feet per plant. The rows were spaced 2, 3, or 4 feet apart and the distance between hills was selected to give the required number of square feet per plant.

The field selected for the experiment was comparatively level and contained approximately 4 acres. The soil type has been classified as Catalina clay by the U. S. Bureau of Chemistry and Soils. Drainage was provided by parallel surface ditches across the field and they were necessary because of the high-intensity rainfall experienced during the months of the summer rainy season in which the corn was grown. To facilitate drainage, the land was plowed in such a way as to mound up the earth in the centers between the surface ditches. Plantings were made on ridges thrown up by the plow at right angles to the ditches and to a height of about 4 inches above the furrow.

In order to provide for statistical analysis of the data collected, a randomized block system of laying out the field was used. Each block contained one plat of each of the six spacing treatments. Twenty-five replications were used making a total of 150 plats or 3.84 acres in the experimental area. Plats measured 36×31 feet, each having an area of 1,116 square feet, or approximately 39 plats to the acre. The layout of the experiment as completed is shown in Fig. 1.

<sup>1</sup>Joint contribution from the Division of Biometry and Plant Physiology and Division of Agronomy, Puerto Rico Experiment Station, U. S. Dept. of Agriculture, Mayaguez, Puerto Rico. Received for publication September 20, 1937.

<sup>2</sup>Biometrician and Plant Physiologist and former Agronomist, respectively. The authors are indebted to Atherton Lee, Director of the Puerto Rico Experiment Station, who suggested and encouraged the investigation; to Wallace K. Bailey, Associate Plant Physiologist, Division of Vegetable Crops, who made the classifications of the ears; and to F. D. Richey, Chief of the Bureau of Plant Industry, for advice and comments.

City of Mayaguez

B1	A2	C3	D4	E5	F6	A7	B8	C9	D10	E11	F12	A13	B14	C15	D16	E17	F18
C19	F20	E21	A22	B23	D24	F25	C26	A27	E28	B29	D30	E31	D32	F33	B34	A35	C36
E37	D38	B39	F40	C41	A42	B43	E44	D45	F46	C47	A48	B49	C50	A51	F52	D53	E54
D55	C56	A57	B58	F59	E60	C61	F62	E63	A64	D65	B66	F67	E68	D69	C70	B71	A72
F73	B74	D75	E76	A77	C78	D79	A80	B81	C82	F83	E84	C85	A86	B87	E88	F89	D90
A91	E92	F93	C94	D95	B96	E97	D98	F99	B100	A101	D102	D103	F104	E105	A106	C107	B108
F109	C110	B111	D112	E113	A114	C115	F116	E117	A118	D119	B120	A121	C22	D123	F124	B25	E126
			A127	F128	C129	E130	D131	C133	F134	A135	E136	D137	B138	A139	C140	D41	F142
				E143	B144	F145	A146	C147	D48	E149	B150	Pennington field					

Symbol	No. of red colters	Plot dimensions feet	Rows per plot	Plants per row	Spacing between rows, feet	Spacing between hills, inches	Area per row square feet	No. of hills per row per plot	Yield per plot	
A	24	32x30x25	16	3	2	12	2	21780	484	480
B	24	32x30x25	16	24	2	15	2.5	17424	387	384
C	24	33x29.3	11	29	3	12	3	14520	323	319
D	24	33x29.3	11	25	3	14	3.5	12446	277	275
E	24	32x30x25	8	30	4	12	4	10890	242	240
F	24	32x30x25	8	27	4	13.5	4.5	9640	215	216

Border rows on three sides of each plot, all plots  $\frac{1}{4}$  acre in area. Fertilizer applied in a band, 720 lbs of 6-6-6 at planting time May 14-18, 1936, and 300 lbs of ammonium sulphate at time of first weeding. Variety U. S. D. A. Experiment planned by Davis and Watson and laid out by Watson. Davis and Rodriguez Inigo. Drainage by Burkhardt.

FIG. 1.—Spacing experiment with sweet corn at the Puerto Rico Experiment Station, U. S. Dept. of Agriculture, Mayaguez, P. R.

Fertilizer of a 6-6-6 formula was applied at the rate of 720 pounds per acre at the time of planting in a band to the side and about 1 inch below the level of the seed. This was followed by 300 pounds of ammonium sulfate 3 weeks after planting. Two cultivations were made with hoes for weed control, one at 3 weeks and the other at time of tasseling, 62 days from planting.

The experiment was harvested 92 days from planting on August 18 to 21, 1936. This was approximately 10 days after the marketable ears in some plats had reached the best edible stage of development. The ears were allowed to become air-dry in the greenhouse and subsequently were classified and weighed. This procedure was followed because rotting frequently is noticed in corn dried on the stalk during the rainy season in the region of Mayaguez. The forage was cut and weighed for each plat immediately after harvesting.

Classification of the ears of USDA-34, a recently bred variety, had previously been confined to a local standard of seed ears and culls. It was desired in the present investigation to classify yields on a basis comparable with yield data from trials at continental experiment stations. Standards were used that had been tentatively formulated by the Bureau of Agricultural Economics for classifying sweet corn intended for canning.

Counts taken at time of harvest showed that there had been considerable modification of the original allotted soil areas per plant because of stand differences. Table 1 shows a comparison of the soil area per plant at time of planting with the observed area per plant at time of harvest.

TABLE 1.—*Comparison of soil area per plant at time of planting and harvest in sweet corn-spacing experiment at Mayaguez, Puerto Rico.*

Treatment symbol	At time of planting			At time of harvest	
	Row distance, inches	Hill distance, inches	Soil area per plant, sq. feet	Stand, %	Average soil area per plant, sq. feet
A	24	12.0	2.0	71.7	2.79
B	24	15.0	2.5	75.8	3.30
C	36	12.0	3.0	88.1	3.41
D	36	14.0	3.5	88.5	3.95
E	48	12.0	4.0	76.3	5.24
F	48	13.5	4.5	75.7	5.94

It is shown in Table 1 that the percentage of stand varied among the various spacing treatments from 71.7 in treatment A to 88.5 in treatment C. These differences in stand among the various treatments must be considered in interpreting the results of an experiment.

#### RESULTS AND STATISTICAL ANALYSIS OF DATA

Table 2 presents the results of the experiment and Tables 3 and 4 the statistical analysis of the results.

TABLE 2.—*Comparative yields obtained with various soil areas per plant in sweet corn-spacing experiment at Mayaguez, Puerto Rico.*

Treatment symbol	Soil area per plant		Marketable ears per acre, number*	Average weight per marketable ear, ounces*	Shelled corn per acre, bushels†	Forage weight per acre at time of harvest, tons
	At time of seeding, sq. feet	At time of harvest, sq. feet				
A	2.0	2.79	2,272	3.827	32.5	3.096
B	2.5	3.30	2,027	3.893	29.0	2.735
C	3.0	3.41	2,269	4.144	32.4	2.944
D	3.5	3.95	1,857	4.066	26.5	2.486
E	4.0	5.24	1,411	4.061	20.2	1.801
F	4.5	5.94	1,347	4.068	19.2	1.883

\*Marketable ears had at least 5 inches of grain, were well filled and formed, and showed no consequential insect damage.

†Shelled corn calculated from air-dry weights of all ears.

#### DISCUSSION OF RESULTS

The method of presentation of data and analysis used in Tables 2, 3, and 4 is believed to simplify the comparison of relative values of treatments in their effect upon the several items of yield.

This form of presentation also provides the reader with data for the critical examination of the experiment as a whole, as shown in Table 3. The significance of the effect of soil variation between blocks containing one plat of each treatment is readily observed in this table. The interaction variance of soil and treatment is used as a measure of error, and the degrees of freedom available for its estimate are included.

TABLE 3.—*Statistical significance of the experiment as a whole.*

Source of variance	Degrees of freedom	Variance* (averaged squared differences from the general mean plat of yields)			
		Market-able ears per acre, number*	Average weight per market-able ear, ounces*	Shelled corn per acre, bushels†	Forage weight per acre at time of harvest, tons
Between treatments.	5	**	**	**	**
Between blocks. . . .	24	**	—	**	**
Interaction (error) . .	120	578	.0002418	.008218	.0002239

\*Marketable ears had at least 5 inches of grain, were well filled and formed, and showed no consequential insect damage.

†Shelled corn calculated from air-dry weights of all ears.

\*Dash (—), single star (\*), and double stars (\*\*) indicate nonsignificance (odds of 20 to 1 or less), significance (odds of less than 100 to 1 and greater than 20 to 1), and high significance (odds greater than 100 to 1), respectively.

TABLE 4.—*Statistical significance of difference between treatments.*

Treatment difference symbols	Comparison of soil areas per plant at time of harvest, sq. feet	Significance of the differences*			
		Market-able ears per acre, number*	Average weight per market-able ear, ounces*	Shelled corn per acre, bushels†	Forage weight per acre at time of harvest, tons
A vs. B	2.79 vs. 3.30	**	—	**	*
A vs. C	2.79 vs. 3.41	—	**	—	—
A vs. D	2.79 vs. 3.95	**	**	**	**
A vs. E	2.79 vs. 5.24	**	**	**	**
A vs. F	2.79 vs. 5.94	**	**	**	**
B vs. C	3.30 vs. 3.41	**	**	**	—
B vs. D	3.30 vs. 3.95	—	*	*	—
B vs. E	3.30 vs. 5.29	**	*	**	**
B vs. F	3.30 vs. 5.95	**	*	**	**
C vs. D	3.41 vs. 3.95	**	—	**	**
C vs. E	3.41 vs. 5.24	**	—	**	**
C vs. F	3.41 vs. 5.95	**	—	**	**
D vs. E	3.95 vs. 5.24	**	—	**	**
D vs. F	3.95 vs. 5.94	**	—	**	**
E vs. F	5.24 vs. 5.94	—	—	—	—

\*Marketable ears had at least 5 inches of grain, were well filled and formed, and showed no consequential insect damage.

†Shelled corn calculated from air-dry weights of all ears.

\*Dash (—), single star (\*), and double stars (\*\*) indicate nonsignificance (odds of 20 to 1 or less), significance (odds of less than 100 to 1 and greater than 20 to 1), and high significance (odds greater than 100 to 1), respectively.

It should be noted that Table 3 was computed from the figures on yields per plat and the variance shown for each yield item is on that basis. The figures in Table 2 presented on the basis of yields per acre in no way change the comparisons of treatments made in Table 4 on the plat basis.

Table 4 is devoted to a comparison of all combinations of pairs of treatments for each item of yield, based upon the respective error variances.

When used in conjunction with Figs. 2 and 3, which portray graphically the results shown in Table 2, the latter table provides a quick and accurate method of appraising the value of any treatment. An example of the ease with which they may be accomplished may be cited. In Fig. 2 it is noted that the total number of marketable ears as

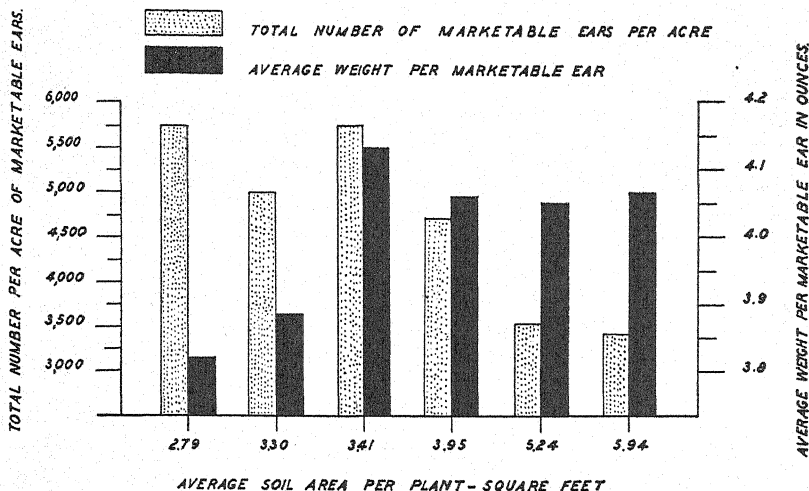


FIG. 2.—Number and average weight per ear of marketable ears produced with various soil areas per plant.

represented by the height of the dotted bar at 3.30 square feet per plant was slightly greater than the number produced with the spacing of 3.95 square feet. Reference to Table 4 under the column heading "number of marketable ears per acre", shows that when 3.30 square feet are compared with 3.95 square feet the difference in numbers of marketable ears produced was not significant as indicated by

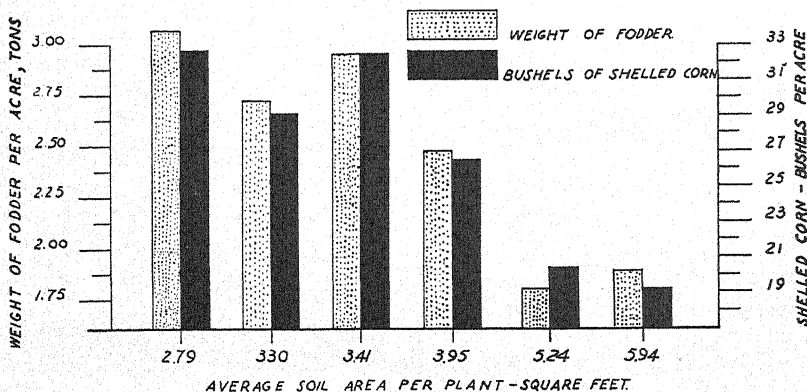


FIG. 3.—Bushels of shelled corn and weight of fodder observed with various soil areas per plant.



the dash (—). Other comparisons suggested by inspection of the chart may be made as readily.

It is apparent in Fig. 3 that there was a marked decrease in production of both fodder and shelled corn when soil areas per plant were greater than 3.41 square feet. The same tendency is noted in Fig. 2 as regards numbers of marketable ears.

The average weight per marketable ear was adversely affected by the smaller areas per plant, although the number of marketable ears was not significantly reduced by the closer spacing. In this experiment the critical area per plant for average weight of marketable ears appeared to lie between 3.30 and 3.41 square feet. When the spacing per plant was increased beyond 3.41 square feet, there was no significant increase in ear weight, and with lessened space per plant the weight was decreased significantly. This is shown graphically in Fig. 2.

The plats for both the 2- and 4-foot-row spacings were plowed into ridges every 2 feet and the 4-foot spacing was obtained by planting on every other ridge. The tillage operations to obtain the spacing of 3 feet between rows resulted in ridges about 9 inches in width at the base. This was approximately 50% wider than the ridges for the 2- and 4-foot-row spacings, which were about 6 inches wide at the base.

The tops of all ridges were leveled by a potato hiller, which resulted in a width of about 2 inches at the top of the ridge of 2- and 4-foot spacings and in a width of about 4 inches in the 3-foot-row spacing. This procedure was justified from the point of view that the difference in width of planting ridge was a part of the treatment difference. However, differences in anchorage were accentuated by a high wind which passed over the field at the time of silking and caused more lodging in the 2- and 4-foot spacings than on the wider ridges of 3-foot spacings. Opportunity was therefore taken to determine comparative lodging in the different treatments and also the effect of the different spacings on average diameter of the corn stalks. These data are presented in Table 5.

TABLE 5.—*Differences in lodging and diameter of stalks observed with various soil areas per corn plant.\**

Treatment symbol	Average soil area per plant at time of planting, square feet	Lodging, %	Average diameter of lowest internode of stalk, cm†
A	2.0	16.7	1.95
B	2.5	18.0	2.01
C	3.0	11.6	2.13
D	3.5	8.2	2.18
E	4.0	15.0	2.18
F	4.5	14.6	2.16

\*These data were recorded by Mr. Jorge Rodriguez Inigo, under scientific aid.

†Based on counts of 10 stalks in each of 20 plats of each treatment.

The data in the last column of Table 5 indicate that a difference of approximately 10% in average diameter of stalks existed between the closest spacing of treatment A and the widest spacing of treatment F. Data were not available for testing the statistical significance of the results shown in Table 5.



This table also shows that better stands and less lodging occurred in treatments C and D which, because of the cultivation requirements of the different spacing treatments, had the widest planting ridges. The lower percentages of lodging of treatments C and D apparently resulted from greater width of planting ridge. Measurements showed practically no difference in stalk diameter between the corn of these treatments and that of treatments E and F.

It has already been shown in Table 1 that modification of the original spacings was caused by differences between the stand at time of planting and stand at time of harvesting. In the case of a 75% stand resulting in approximately the same average area per plant at time of harvest as another spacing treatment with 90% stand, the latter treatment might be expected to have higher yields per plant because of better land utilization by the individual plants. It is believed that such a factor was operating in this experiment, resulting in superior yields of treatment C over treatment B.

It is interesting to note that series E and F gave almost the same results for all items of yield. Apparently the treatment having the larger area per plant yielded enough more per plant to compensate for the smaller number of plants per acre it contained.

In treatments C and D, with practically equal stands, competition was becoming more severe with less soil area per plant, but for all yield items, except average weight of marketable ear, the closer of the two spacings, or 3.41 square feet per plant, yielded better.

A comparison between treatments A and B cannot be made so logically because of differences in percentage stand. The closer spacing continued to increase numbers of marketable ears, weight of shelled corn, and forage weights. Moreover, the decrease of weight of marketable ear was not statistically significant. However, the sharp drop noted in this weight when soil areas per plant decreased below 3.41 square feet would probably eliminate the closer spacing from consideration for growing the USDA-34 variety of sweet corn at this station.

Because of numerous biological factors which enter in to reduce stands in corn experiments in the vicinity of Mayaguez, the practice is now being followed of planting rows 3 feet and hills 1 foot apart with final thinning to one plant per hill. Three square feet per plant at time of planting then increases to approximately 3.4 square feet with usual reductions in stand.

The large number of replications used was based on the principle that the smaller the experimental differences expected, the greater must be the number of replications. With the large numbers of replications in this experiment, it is felt that in the case of yield differences which were nonsignificant, the spacing practice to be followed would depend on economy rather than on yields.

#### SUMMARY AND CONCLUSIONS

1. An experiment in spacing, using six different soil areas per plant, was conducted with the USDA-34 variety of sweet corn to determine the effect of spacing on numbers and weight of marketable ears, yields of shelled corn, and forage weights. Plantings were made on

ridges with one plant per hill. Variation in soil area per plant was accomplished by varying both the row and hill planting distances. The experiment, which contained 25 replications of the plats of each treatment, was designed to provide for statistical analysis of the results.

2. The closest spacing used, or 2.79 square feet of soil area per plant at time of harvest, gave the highest yield of shelled corn and fodder.

3. Increasing numbers of marketable ears were noted as the soil area per plant became smaller, but this was attended by a significant decrease in average weight per marketable ear when the area was less than 3.41 square feet per plant.

4. Planting ridges 4 inches wide at the top and 9 inches wide at the base showed less lodged corn after a high wind than ridges which measured 2 inches at the top and 6 inches at the bottom.

5. Diameter of lowest internode of corn stalks increased with increase of the soil areas up to 3.95 square feet per plant. Further increases in area per hill did not result in increased diameters of the stalks.

## NUT GRASS ERADICATION STUDIES: II. THE ERADICATION OF NUT GRASS, *CYPERUS ROTUNDUS* L., BY CERTAIN TILLAGE TREATMENTS<sup>1</sup>

E. V. SMITH AND E. L. MAYTON<sup>2</sup>

IN an effort to eradicate any troublesome weed, the best procedure would seem to be to study fully the life history of the pest in the hope of finding periods in its life cycle at which it is most susceptible to attack. Accordingly, the eradication studies on the nut grass plant, *Cyperus rotundus* L., reported in this and later papers, represent an outgrowth of the life history studies reported by Smith and Fick.<sup>3</sup> Their results showed that nut grass reproduces itself principally, if not solely, by tubers and basal bulbs. It was shown also that this plant forms a rather complex system of aerial and underground parts all of which act as a physiological unit. The tubers and basal bulbs which represent a part of the underground system do not all germinate unless each tuber or basal bulb is separated from the rest of the system. Data are also given showing that exposure of these parts to drying was very effective in reducing their viability.

Consequently, it seemed reasonable that the following of a systematic schedule of tillage treatments on nut grass-infested land might be effective in eradicating this pest. Such treatments would tend to break apart the plant systems and expose many of the isolated tubers and basal bulbs to drying at or near the surface of the soil. Other tubers in more moist soil would be stimulated to germinate as a result of isolation. Smith and Fick<sup>4</sup> also presented data which showed that in a sandy soil less than 1% of the viable tubers was below the possible plow depth. This fact is of particular advantage in tillage treatments.

### EXPERIMENTAL

In order to study the effects of tillage treatments on nut grass a series of nine plats, each 20 by 110 feet, was laid out in a rather heavily infested area of Norfolk sandy loam soil in 1934. The original infestation of each plat was determined by screening out the tubers in the surface soil (approximately 8 inches) of three definitely located areas, each 2 by 2 feet. In preliminary work it was found that this method was the best to use in determining the infestation of an area. A count of aerial shoots is unreliable because of a much greater potential infestation represented in dormant underground tubers. The live tubers were determined by paring off small slices with a knife or slitting them with the thumb nail and noting the color. In laboratory work with tubers it had been found that only the firm, crisp tubers showing little or no discoloration on the inside were capable of germinating.

<sup>1</sup>Contribution from the Departments of Botany and Plant Pathology and of Agronomy and Soils, Alabama Agricultural Experiment Station, Auburn, Ala. Published with the approval of the Director as part II of a Series. Received for publication October 2, 1937.

<sup>2</sup>Associate Botanist and Assistant Agronomist, respectively.

<sup>3</sup>SMITH, E. V., and FICK, GEORGE L. Nut grass eradication studies: I. Relation of the life history of nut grass, *Cyperus rotundus* L., to possible methods of control. Jour. Amer. Soc. Agron., 29:1007-1013. 1937.

<sup>4</sup>*Loc. cit.*

The infestation records were taken early in June, 1934, and the tillage treatments were begun on June 9 and extended throughout October. The various plats were either plowed or disked at regular intervals with one plat being left untilled as a control. The plow used was of the moldboard type which leans the furrow slice against a previous one instead of completely inverting it. The disk harrow used was the two-horse type equipped with ten discs approximately 16 inches in diameter. In the disking operation the plats were "double-cut" at each disking.

Separate plats were plowed or disked at 1-, 2-, and 4-week intervals throughout the season. One plat was plowed and another was disked when sprouts were general over the area. The interval between tillage treatments on the plats throughout 1934 was approximately 3 weeks. The same treatments were begun on April 24, 1935, and again extended throughout October. The plowing and disking operations were done as nearly on schedule as weather conditions would permit and in no instance did they vary from the specific date more than three days.

Infestation records were again taken on three definitely located 2 by 2 foot areas (each adjacent to a previously dug area) at the end of the 1934 season and at the beginning and end of the 1935 season. These data are presented in Table 1.

TABLE 1.—*The effect of tillage treatments on the infestation of nut grass.*

Plat No.	Treatment	Number of live tubers*		Percentage reduction during 1st season	Number of live tubers*		Percentage reduction over two seasons
		Beginning of experiment June 1, 1934	End of 1st season Nov. 17, 1934		Beginning of 2nd season April 13, 1935	End of 2nd season Dec. 14, 1935	
1	Plowed every week	80	15	81	15	0	100
2	Plowed every 2 weeks	87	14	84	17	0	100
3	Plowed every 4 weeks	66	119	+80	66	1	98
4	Plowed whenever sprouts were general over area	71	14	80	13	4	94
5	No treatment	46	145	+220	146	191	+315
6	Disked every week	41	10	76	6	0	100
7	Disked every 2 weeks	67	14	79	15	0	100
8	Disked every 4 weeks	44	45	+2	18	13	70
9	Disked whenever sprouts were general over area	67	14	79	7	0	100

\*Each figure is the average of three 2 by 2 foot diggings.

## RESULTS

The data in Table 1 show that nut grass was either completely eradicated or very nearly eradicated on all treated plats except the one disked every 4 weeks. On the plats plowed or disked every week, every second week, or whenever sprouts were general over the area, the infestation was reduced approximately 80% during the first season. An increase in infestation during 1934 is shown where tillage operations were at 4-week intervals, but the infestation records in the spring of 1935 indicate a rather high mortality during the winter.

Since a new tuber is formed in approximately 3 weeks, the majority of the live tubers from the fall diggings of 1934 on plats 3 and 8 were very small. Such newly formed tubers contain a very low food reserve and a high mortality was to be expected. There was a steady increase in infestation throughout the two years on the control plat.

The indication of eradication by the tillage treatments was so striking that it was thought advisable to check the results shown in Table 1 by determining the infestation on a larger area of each plat. Accordingly, in March, 1936, the surface soil from the center one-fourth of each plat was screened and the number of live and dead tubers determined. These results are presented in Table 2. With the exception of the tubers from the control plat, all tubers which were apparently alive were brought into the laboratory and placed in a germinator; thus the number of live tubers shown in Table 2 is the number which actually produced new plants. These data show that nut grass was completely eradicated by plowing treatments at intervals of 3 weeks or less over two consecutive growing seasons. The disking treatments were almost as effective.

TABLE 2.—*Final tuber infestation following tillage treatments for two successive growing seasons.*

Plat No.	Treatment	Tuber infestation, March 1936*	
		No. of live tubers	No. of dead tubers
1	Plowed every week	0	Not determined
2	Plowed every 2 weeks	0	2,490
3	Plowed every 4 weeks	13	5,202
4	Plowed whenever sprouts were general over plat	0	1,940
5	No treatment	17,377	9,559
6	Disked every week	1 (sprout very weak)	1,838
7	Disked every 2 weeks	0	3,093
8	Disked every 4 weeks	67	3,794
9	Disked whenever sprouts were general over plat	5	754

\*Areas dug were 10 by 55 feet.

All plats were left undisturbed during the 1936 season to see if any nut grass came back on the different plats. At each end of each plat an area 10 by 13¾ feet was staked for regular observations during this season as a final check on the efficiency of the plowing and disking treatments. Observations were made at 2-week intervals beginning June 18 and ending September 1. No plants occurred on plats which had been plowed at 1- or approximately 3-week intervals. A total of eight plants developed on the plat plowed at 4-week intervals and one plant on the plat plowed every 2 weeks. This plant was carefully dug and found to arise from a tuber 12 inches below the soil surface. This tuber had apparently lain dormant in the soil for 2½ years. No plants were found on the plats disked at intervals of 1, 2, or approximately 3 weeks. On the plat disked every 4 weeks, a total of 150 plants was found on the two small areas. At the end of the season this plat carried a generally light infestation over its whole area.

## DISCUSSION

The results of this experiment indicate that it is possible to eradicate nut grass on sandy soils by either plowing or disking at intervals of 3 weeks or less throughout two successive growing seasons. Such treatments would of course prevent the growing of a summer crop on the land, but a winter grain or hay crop which is planted in October and harvested by the first of June might be grown. Such a crop, in fact, would be desirable because land fallowed throughout the summer is very susceptible to erosion losses in the winter and a winter crop would give considerable protection. Nut grass will make very little growth in a dense crop of grain or winter legumes and tillage treatments would not be seriously delayed by such crops.

Intensive tillage treatments may not be feasible on a whole farm infested with nut grass, but they are very practical when small areas occur in fields. Such areas serve to infest the whole field in the course of a few years. A considerable amount of labor and time may be very wisely spent on the eradication of nut grass from small areas before it spreads to larger areas. The use of tillage treatments here described offers a means for complete eradication of nut grass on light sandy soils.

## SUMMARY

Studies on the eradication of nut grass by tillage treatments are presented. It was found that plowing or disking at intervals of 3 weeks or less during two consecutive growing seasons completely eradicated nut grass on a Norfolk sandy loam soil. Such treatments reduced the infestation approximately 80% the first year.

## THE VALUE OF COVER CROPS IN CONTINUOUS CORN CULTURE<sup>1</sup>

T. E. ODLAND AND H. C. KNOBLAUCH<sup>2</sup>

THE use of cover crops for the purpose of conserving soil fertility, whenever possible, is becoming a general practice on the better managed farms in Rhode Island as well as in many other localities. Specific evidence on the value of such practice over a considerable period of time is, however, not so plentiful. Results obtained with nonlegume cover crops have sometimes been contradictory. The purpose of this paper is to present some results from a long-continued experiment with rye and clover cover crops in continuous corn culture at the Rhode Island Agricultural Experiment Station.

Pieters<sup>3</sup> has reviewed the literature on green manuring for various crops and with the use of different green manure and cover crops. Generally, very beneficial results have been obtained from legume green manure crops. Nonlegume crops, especially rye, have not always been of benefit to certain succeeding crops. In several instances the results reported showed a detrimental effect of a rye cover or green manure crop on a succeeding crop of corn.

More recently, Sprague<sup>4</sup> has reported results obtained with seven different green manure crops used with continuous corn over a 5-year period. The legume green manure crops used showed beneficial effects on the succeeding corn crops, but no increase in yield over the check plot was obtained from the use of wheat or rye.

### DESCRIPTION OF EXPERIMENT

The experiment in continuous corn culture was begun in 1894. The purpose, as stated in an early bulletin from the Rhode Island Station, was to determine the "feasibility of attempting to grow corn or other plants continuously upon the same land without the introduction of intermediate crops or the use of farm manures, the sole dependence for the maintenance of fertility to be placed upon commercial fertilizers". This experiment was continued until 1933 under this plan. The area included consisted of 1 acre of land. The soil is classified as Bridgehampton very fine sandy loam, is underlain by gravel, and is well drained.

In 1898 this acre was divided into four equal parts for the purpose of comparing legume and nonlegume cover crops with no cover crop. Two sections, 2 and 4, were left without cover crops; one section, 3, had rye sown in the corn at the last cultivation and another section, 1, had a legume cover crop seeded at the same time.

In 1915 the test was modified in that the amount of nitrogen applied in the fertilizer was considerably increased on all sections except the one seeded annually to a legume cover crop.

In 1922 another change was made in that on section 4 the ears were husked from the standing corn and the stalks later plowed under. For three years previous to

<sup>1</sup>Published by permission of the Director of Research, Rhode Island Agricultural Experiment Station as Contribution No. 511. Received for publication October 8, 1937.

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<sup>3</sup>PIETERS, A. J. *Green Manuring*. New York: John Wiley & Sons Inc. 1927.

<sup>4</sup>SPRAGUE, H. B. The value of winter green manure crops. N. J. Agr. Exp. Sta. Bul. 609. 1936.

this, straw had also been applied to this section. A more detailed description of the test with results obtained to 1918 may be found in Bulletins 113 and 173 of the Rhode Island Experiment Station.

In this paper the results obtained during the years 1900 to 1933, inclusive, will be considered. The crop for 1899 is omitted since this was the first year after the change to the plan of using no cover crops on two sections.

The fertilizer applied has varied considerably. The average application for the period of 1900 to 1933 was approximately 1,200 pounds per acre of a 5-8-7 fertilizer on sections 2, 3, and 4. Since 1915 only about one-third to one-half as much nitrogen was applied to section 1 receiving the legume cover crop. In 1926 section 3 was again divided into north and south halves and an increased amount of nitrogen applied in the fertilizer on the north half. The yield figures for the different sections presented in this paper are based on the south half only of this section for the years since that time. This half continued to receive the same amount and kind of fertilizer as sections 2 and 4.

The amount of fertilizer used is somewhat more than is ordinarily applied for corn where this is grown in a rotation with other crops. The heavy application was used in order to eliminate the factor of insufficient soil nutrients as far as possible.

Lime has been applied at four different times during the course of the experiment. The total amount has been the equivalent of about 6 tons of ground limestone per acre. In addition, a total of nearly 3 tons per acre of wood ashes were used over the period 1918 to 1921 to supply potash. This would be the equivalent of approximately 2 tons of limestone in its effect on soil acidity. Basic slag was used frequently during the early years of the experiment as the source of phosphoric acid. The total amount used carried an equivalent of approximately  $1\frac{1}{2}$  tons per acre of limestone. During the course of the experiment, therefore, a total of soil acidity correctives to the extent of about  $9\frac{1}{2}$  tons of limestone per acre have been added. This has resulted in maintaining a pH of about 6.5 over the greater part of the time. Section 1 has been inclined to show the greatest amount of soil acidity whenever tests have been made. The differences have been small, however, among the four sections.

The soil on which this experiment was located is fairly uniform, although it is somewhat deeper and heavier on section 1 which is on the east side. Westward through sections 2, 3, and 4 the soil becomes a little more shallow and lighter. Although these differences are not great they should be kept in mind when considering the results obtained.

The legume cover crops have consisted of different clovers, either alone or in mixtures with winter vetch or winter vetch and alfalfa. A mixture of red, alsike, and sweet clover was the predominant cover crop during the last 10 years of the test. During the first 24 years, crimson clover was usually used either alone or in mixtures with winter vetch and other clovers. The cover crops have generally been seeded in the corn during the first week in August and plowed under the middle of the following May.

The growth of the legume cover crop was not very satisfactory some years, while in others a good cover was obtained. Winter injury to the cover crops varied with the seasons and with the crop used. A mixture of red, alsike, and sweet clover was the one finally adopted as the most reliable under local conditions.

The winter rye used each year as a cover crop on section 3 has usually been seeded at the rate of 70 pounds per acre at the last cultivation of corn. The growth obtained before plowing under has varied from a few inches in height to as high as 2 feet.



At harvest time the corn was husked, weighed, and acre yields of shelled corn computed. The ears were separated into hard and soft corn on the basis of maturity.

In 1934, this test was discontinued in order to make the space available for other experimental work. Enough soil was taken from each section, however, to fill a "cement frame" approximately 5 feet by 10 feet in size to a depth of 8 inches. The original plan of cover crops and fallowing is being continued in these frames.

#### YIELD OF GRAIN

The yields obtained for the years 1915 to 1933, inclusive, are presented in Table 1. The average yield for the periods of 1900 to 1905 and 1906 to 1914, as published previously, are also shown.

TABLE 1.—*Yields of corn grown continuously with and without cover crops at the Rhode Island Agricultural Experiment Station, Kingston, R. I., in bushels per acre.\**

	Hard corn				Soft corn				Stover			
	Section 1	Section 2	Section 3	Section 4	Section 1	Section 2	Section 3	Section 4	Section 1	Section 2	Section 3	Section 4
Ave. 1900-1905†	43	31	35	29	5	5	5	6	1.9	1.5	1.8	1.7
Ave. 1906-1914†	43	25	28	16	6	5	4	4	1.8	1.4	1.6	1.3
1915	56	38	42	28	7	6	7	8	3.0	2.1	2.8	2.0
1916	19	7	14	4	5	3	7	8	1.3	1.2	1.5	1.3
1917	41	28	33	18	10	12	13	12	2.1	1.2	1.2	1.2
1918	54	47	53	45	4	3	3	5	1.7	1.5	1.7	1.9
1919	40	32	43	42	4	6	5	5	1.8	1.9	2.3	2.4
1920	48	28	35	26	4	4	5	5	2.1	2.0	2.2	2.1
1921	81	52	68	51	3	3	2	3	3.1	2.3	2.3	2.4
1922	44	36	38	29	3	2	4	6	2.2	2.4	2.4	—
1923	31	33	35	39	7	4	5	4	1.5	1.5	1.6	—
1924	18	15	15	16	6	7	7	8	2.2	1.8	2.2	—
1925	39	53	53	63	2	2	1	2	2.6	2.8	3.0	—
1926	48	57	70	65	4	3	4	4	4.0	3.7	4.1	—
1927	31	33	36	31	2	1	1	2	3.0	2.9	3.0	—
1928	54	43	52	46	4	3	3	4	4.2	3.7	5.0	—
1929	54	57	67	67	1	1	1	4	2.2	2.3	3.2	—
1930	20	21	31	26	5	5	6	6	2.7	2.8	3.6	—
1931	33	39	48	36	5	5	8	5	1.9	2.2	2.4	—
1932	67	32	36	35	3	3	3	2	3.0	2.3	3.0	—
1933	33	36	52	35	—	—	—	—	2.8	2.9	3.2	—
Ave. 1915-1933	43	36	43	37	4	4	4	5	2.5	2.3	2.7	—
Ave. 1900-1933	43	32	38	30	5	4	4	5	2.2	1.9	2.2	—

\*Section 1 = Legume cover crop; Section 2 = No cover crop; Section 3 = Rye cover crop; and Section 4 = No cover crop (corn stover plowed in beginning in 1922).

†See R. I. Agr. Exp. Sta. Bul. 173.

The average total yields of shelled corn, hard and soft, for the first 6-year period, 1900 to 1905, were 48, 36, 40, and 35 bushels per acre, respectively, following the legume cover crop, fallow, rye, and fallow. If the two adjoining sections, 1 and 2, are compared, it will be seen that an increase of 12 bushels per acre was obtained by the use of the legume cover crop. An increase of 4 bushels per acre was obtained from the rye cover crop when this is compared with the same check or fallow section.

For the 9-year period of 1906 to 1914, the average yields on the same sections were 49, 30, 32, and 20 bushels, respectively. Here again the legume cover crop produced a very sizable increase in yield over the adjoining fallow sections. The average increase in yield obtained on the rye cover crop section was only 2 bushels over that on fallow section No. 2, but 12 bushels over that on section 4 which was also one without a cover crop. Although the soil becomes gradually somewhat lighter from section 1 to 4, this does not seem a sufficient reason for the low yield on section 4 over this period. The cause of this low average yield is not evident.

The average annual yields of shelled corn for the 19-year period of 1915 to 1933 were 47, 40, 47, and 42 bushels per acre on sections 1, 2, 3, and 4, respectively. During this period the first section where the legume cover crop was used received only one-third to one-half as much nitrogen in the fertilizer as was applied to the other sections. Since the plan of plowing under the stover on section 4 was introduced during this period, the yields on this section cannot be used for a strict comparison with the other uniformly treated sections.

Despite the fact that the nitrogen applied to section 1 was considerably reduced, the yields were maintained so that the average on this section was the same as on section 3 with the rye cover crop and considerably heavier nitrogen fertilization. These two sections out-yielded the fallow section, No. 2, by an average of 7 bushels of shelled corn per acre. In both cases the odds<sup>5</sup> show this to be a significant increase in yield over the no cover crop section.

When the yields over the entire 34-year period, 1900-1933, are compared, the average yields are 48, 36, 42, and 35 bushels of shelled corn per acre for sections 1, 2, 3, and 4, respectively. Only section 2 with no cover crop and section 3 with a rye cover crop can be strictly compared over this period. The south half of section 3 was used for the comparison since 1926. The sections have received the same amount of fertilizer and were otherwise treated alike over the entire period with the exception of the rye cover crop. Section 1 is not strictly comparable due to the change made in nitrogen applied in the fertilizer and section 4 has been partly left fallow and partly had the corn stalks plowed in.

Over the entire 34-year period the average increase in yield of section 3 with the rye cover crop over that of section 2 without a cover crop has been 6 bushels of shelled corn per acre. When the odds are calculated, it is found that the chances are over 10,000 to 1 that this is a significant increase in yield. This increase in yield can definitely be accepted as being due to benefits derived from the cover crop since several uniform crops of corn previous to the beginning of the experiment had shown that the soil where sections 1 and 2 are located was a little higher in yielding capacity than the soil where sections 3 and 4 are located. Examination of the soil profile also shows section 2 to have a little deeper and heavier topsoil than section 3. The higher

<sup>5</sup>Odds less than 30 to 1 not considered significant. Odds calculated according to Student's method as reported by Love, H. H., in "A modification of Student's table for use in interpreting experimental results", Jour. Amer. Soc. Agron., 16: 68-73. 1924.

yields on section 1, however, should perhaps be discounted a little due to its being a slightly heavier soil type than that of section 2. The variation in the original fertility of soil, however, was not large and ordinarily it would be considered very uniform in this respect.

The cause of detrimental effects noted on crops from a previous nonlegume cover or green manure crop has often been ascribed to a competition of the decaying vegetable matter and the growing crop for the available soil nitrogen. Addition of more nitrogen in the fertilizer to supply enough both for the decaying vegetable matter and the growing crop has been suggested as the remedy. Examination of the data where adverse results from rye and other nonlegume green manure crops have been reported often shows that failure to provide sufficient nitrogen in the fertilizer could easily be an explanation of the results obtained.

Although what was considered to be a very liberal application of nitrogen was applied to the corn crops in this experiment from its beginning, it was decided in 1926 to add even more on one-half of the rye cover crop section. This section was therefore divided and 25% more nitrogen applied to the north half than was applied on the other half and on the fallow section. In 1927 and subsequent years 50% extra was applied instead of 25%. The yields on the two halves are shown in Table 2.

TABLE 2.—*Total yields of corn on section 3, 1926 to 1933, in bushels per acre.*

Year	North half, extra nitrogen	South half, regular nitrogen
1926.....	77	74
1927.....	50	37
1928.....	64	55
1929.....	95	68
1930.....	55	37
1931.....	74	56
1932.....	55	39
1933.....	59	52
Average.....	66	52

The yields obtained show that a material increase resulted nearly every year. The average annual increase in yield for the extra nitrogen was 14 bushels per acre. This extra yield was obtained from an additional 30 pounds of nitrogen applied annually in the fertilizer. These results indicate that even a greater benefit would have been shown by the rye cover crop if a fertilizer higher in nitrogen had been used throughout the test. Other experiments at this station have repeatedly shown that crops respond best, in general, to generous fertilizer applications when the soil is well supplied with organic matter. The additional 14 bushels of shelled corn was a well worthwhile return on the additional nitrogen applied in the fertilizer.

#### YIELD OF STOVER

The yields of stover have varied considerably from year to year on this experiment. In general, the yields of stover have been in the

order of the yields of grain on the corresponding sections. For the entire 34-year period, the average yield on section 1 with the legume cover crop was 2.2 tons of field dried stover per acre (Table 1). The same average was produced on section 3 with a rye cover crop but with more nitrogen applied in the fertilizer. The average yield on the fallow section, No. 2, was 1.9 tons per acre. The rye cover crop apparently was effective in producing an increased yield of stover as well as grain when compared with the fallow section.

## EFFECTS OF COVER CROPS ON THE SOIL

### NITROGEN CONTENT

Total nitrogen determinations have been made on the soil from the different sections of this experiment at various times.<sup>6</sup> One of the benefits that presumably should be derived from the use of cover crops is the maintenance of the soil organic matter which in turn should be reflected in the total nitrogen content of the soil. The nitrogen determinations made in 1914 and 1932 are shown for comparison in Table 3. No determinations previous to 1914 are available.

TABLE 3.—*Total nitrogen in soil of continuous corn experiment.*

Section No.	Percentage N		Pounds N per acre	
	1914	1932	1914	1932
1.....	0.1947	0.1763	3,894	3,526
2.....	0.1326	0.1180	2,652	2,360
3.....	0.1353	0.1332	2,706	2,664
4.....	0.1160	0.1199	2,320	2,398

The results of the nitrogen determinations show that in 1932, after 40 years of continuous cropping to corn, the total nitrogen where no cover crop was used had been reduced to a very low level. The total nitrogen content on this section had been reduced to 0.1180%. Soil of this type in adjoining plats where crop rotation and adequate fertilization is practiced will average about 0.20% total nitrogen. The total nitrogen content on section 1 had been reduced from 0.1947% in 1914 to 0.1763% in 1932. Section 2 without a cover crop was reduced from 0.1326 to 0.1180%, while on the rye cover crop section, No. 3, the reduction was only from 0.1353 to 0.1332%. Section 4 was very low at both sampling dates, but showed a small gain. This could be accounted for on the basis of the plowing under of the stover during the last 12 years of the test. Both the legume cover crops and rye alone have helped in preventing the total nitrogen content from becoming depleted as rapidly as where no cover crop was used.

When the percentages are translated into pounds of nitrogen per acre as shown in the table, the range is from 2,320 to 3,894 pounds per acre in 1914 and from 2,360 to 3,526 pounds in 1932. This again brings out the fact that the rye cover crop has decidedly reduced the

<sup>6</sup>The authors are indebted to John B. Smith for nitrogen and moisture determinations. The Kjeldahl-Gunning-Arnold method for total nitrogen was used.

rate of loss of organic matter from the soil as measured by total nitrogen content and compared with the fallow section.

#### MOISTURE

Soil organic matter is of benefit to crops in adding to the water-holding capacity of the soil. If green manuring and the growing of cover crops help to conserve the organic matter of the soil they should also help to maintain a better water-holding capacity.

In this experiment it has been generally observed that the sections with cover crops have apparently suffered less from dry spells than those without cover crops. In order to check on the actual moisture-holding capacities of these different sections, moisture determinations were made at various times. Section 2 with no cover crop and section 3 with the rye cover crop were generally used for making these determinations. In the years 1926, 1927, and 1928 a series of soil moisture determinations were made on these two plots over a period of several months each summer. The results are shown in Table 4.

TABLE 4.—*Soil moisture determinations on sections 2 and 3 during the seasons of 1926 to 1928, inclusive.*

Year	Number of determinations	Period covered	Average percentage of moisture	
			Section 2, fallow	Section 3, rye cover crop
1926.....	4	June-Aug.	19.0	22.1
1927.....	10	Apr.-Aug.	23.8	27.4
1928.....	7	June-Aug.	23.9	28.1

As may be seen from these figures, the rye cover crop on section 3 had increased the water-holding capacity so that on an average the soil contained from 3 to 4% more water than on the fallow section. When the moisture content of the soil is at a critical point for the crop this additional water-holding capacity may mean considerable in the final yield.

#### SUMMARY AND CONCLUSIONS

Corn was grown continuously over a period of 40 years with a comparison of both legume and nonlegume cover crops and no cover crop. Variations in fertilization and disposition of the corn stover were also included.

The legume cover crops were the most effective in maintaining the yields of corn in this test.

Winter rye seeded at the last cultivation of the corn in the fall increased the average annual yield by 6 bushels per acre over the adjoining no-cover-crop section for the 34 year period of 1900-1933.

The yields of stover were increased by both the legume and rye cover crops. The increase in yield of stover was not as large in proportion, however, as the increase in yield of grain.

Increasing the nitrogen content in the fertilizer by 50% on one-half of the rye cover crop section resulted in an average annual increase

of 12 bushels per acre over the half with the regular amount of nitrogen.

The total amount of nitrogen in the soil showed a gradual decrease on all sections. Both the legume and rye cover crops lessened the rate of decrease in total nitrogen.

The cover crops used increased the water-holding capacity of the soil.

This experiment has definitely shown that under conditions such as prevail where this test was conducted the practice of using cover crops for conserving soil productivity is a highly desirable practice and should be encouraged. Where a legume cover crop can be used successfully this is to be preferred. Rye, although a nonlegume, will also show decided benefits to the soil and crop grown.

## CHANGES IN COMPOSITION OF GRANULAR AND POWDERED FERTILIZERS IN THE SOIL<sup>1</sup>

CHARLES B. SAYRE AND ARTHUR W. CLARK<sup>2</sup>

RECENTLY there has been a marked increase in the use of granulated fertilizers accompanied by an increasing interest in the physical and chemical properties of the granulated forms as compared with ordinary powdered forms of fertilizers. Consequently, some studies were undertaken at the New York State Experiment Station at Geneva to determine the relative rates of solution and the changes that take place in granulated and powdered fertilizers after they have been applied to the soil.

In a previous publication,<sup>3</sup> the authors have shown the rates of solution of 23 different kinds of fertilizers and some changes that take place in the first 2 weeks after these fertilizers are applied to the soil. However, no granular fertilizers were used in the previous tests, and the changes over a longer period were not studied.

Mehring, *et al.*,<sup>4</sup> studied the relation of particle size to action in the soil by analyzing soil to which fertilizers of varying particle size had been applied 100 days previously. They reported that, "Comparison of the determinations directly is not satisfactory since the fertilizer was mixed with different amounts of soil in each sample".

The authors sought to overcome this difficulty by a different method of approach, that is, analyzing the fertilizer residues which had been kept separate from the soil. This was accomplished by placing the fertilizers in bands about 2 inches wide and  $\frac{1}{8}$  inch thick between strips of Monel metal wire cloth buried in the soil 4 inches deep so that the fertilizers would be exposed to the natural action of the soil solution, yet could be recovered from the soil later without appreciable contamination. Three different fertilizer mixtures each in powdered form and in three sizes of granules were used in this test. Analyses were made of the residues of these fertilizers recovered from the soil after they had been in the field for 2 weeks, 16 weeks, and 1 year. The soil was Ontario loam having a pH of 6.9.

The fertilizer mixtures used in this experiment were prepared and granulated by Dr. H. W. Ross of the Bureau of Chemistry and Soils, U. S. Dept. of Agriculture at Washington. The amount of each ingredient used in preparing a ton of each fertilizer is shown in Table 1.

Each of the above formulas was prepared in powdered form and in three sizes of granules. The powdered form would pass a 40-mesh screen, the large size granules (suffix A) would pass a 4-mesh but not a 5-mesh screen, the medium size

<sup>1</sup>Contribution from the Divisions of Vegetable Crops and Chemistry, New York State Agricultural Experiment Station, Geneva, N. Y. Approved for publication by the Director as Journal Paper No. 220. September 15, 1937. Also presented before the Fertilizer Section American Chemical Society, Rochester, N. Y., September 10, 1937. Received for publication October 11, 1937.

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<sup>3</sup>SAYRE, C. B., and CLARK, A. W. Rates of solution and movement of different fertilizers in the soil and the effects of the fertilizers on the germination and root development of beans. N. Y. State Agr. Exp. Sta. Tech. Bul. 231. 1935.

<sup>4</sup>MEHRING, A. L., WHITE, L. M., ROSS, W. H., and ADAMS, J. E. Effects of particle size on the properties and efficiency of fertilizers. U. S. D. A. Tech. Bul. 485. 1935.



TABLE 1.—Amount of ingredients in fertilizers used.

Material	No. 243, 5-20-5, lbs.	No. 244, inorganic N, 5-10-5, lbs.	No. 245, organic N, 5-10-5, lbs.
Superphosphate 19.6 . . . . .	640	816	816
Treble superphosphate 46.7% . . . . .	588	86	86
Ammonia . . . . .	60	30	30
Ammonium sulfate 20.8% . . . . .	192	288	192
Sodium nitrate 16.3% . . . . .	61	92	61
Cottonseed meal 7.2% . . . . .	0	0	347
Muriate of potash 57.7% . . . . .	173	173	173
Dolomite . . . . .	286	340	286
Filler (sand) . . . . .	0	175	9
Total . . . . .	2,000	2,000	2,000

granules (suffix B) would pass a 5-mesh but not a 10-mesh screen, while the small granules (suffix C) would pass a 10-mesh screen but not a 20-mesh screen.

Repeated trials proved that it was impossible to recover fertilizers in powdered form that had been in direct contact with the soil without varying and rather large admixtures of soil. In previous tests,<sup>5</sup> fertilizers had been placed between strips of cheesecloth in the soil, but it was found that the cheesecloth disintegrated after about 3 weeks, particularly if organic fertilizers were used. Consequently in the tests reported on here the fertilizers were placed in the soil between strips of Monel metal wire cloth because it was thought this metal cloth would resist the corrosive action of the soil and fertilizers for a long time. This metal cloth was made of 0.006 inch Monel metal wire woven in a 60×50 mesh. It was very flexible and water passed through it readily.

Six lots of each size of each fertilizer were placed between the metal cloth strips buried 4 inches deep in the soil in the field. After 2 weeks, 16 weeks, and 1 year two lots of each fertilizer were removed from the soil and analyzed separately. The fertilizers were placed in the field in May, 1936. The 16-week period covered the normal growing season of many vegetable crops. The analyses of the original fertilizers and of their residues recovered from the soil after 2, 16, and 52 weeks are given in Table 2, which shows the average analyses of two lots of each fertilizer. There was very close agreement in the analyses of the duplicate lots. All analyses were made by the junior author and his associates, Messrs. Kokoski, Willits, and Norton of the Fertilizer Control Laboratory.

## RESULTS

Although powdered fertilizers could not be cleanly recovered after being in direct contact with the soil, it was possible after a great deal of careful and tedious work with tweezers to recover granulated fertilizer that had been in intimate contact with the soil. Two granulated 5-10-5 fertilizers, *viz.*, No. 244B having all its nitrogen in mineral form and one No. 245B in which 25% of its nitrogen was in organic form, were thus recovered and analyzed. These had been placed in the soil without any strips of metal cloth but were in direct contact with the soil and were recovered after 14 weeks in the soil and the analyses of these residues are also given in Table 2.

<sup>5</sup>See footnote 3.



TABLE 2.—Analyses of powdered and granulated fertilizers recovered from the soil.

Material	N, %	Total P <sub>2</sub> O <sub>5</sub> , %	Insol. P <sub>2</sub> O <sub>5</sub> , %	Avail. P <sub>2</sub> O <sub>5</sub> , %	Wa- ter- sol. P <sub>2</sub> O <sub>5</sub> , %	K <sub>2</sub> O, %
No. 243A: 5-20-5 granulated						
4 to 5-mesh. ....	4.88	20.73	0.23	20.50	10.55	5.17
Residue after 2 wks. in soil*. ....	0.39	19.00	1.64	17.36		1.00
Residue after 16 wks. in soil†. ....	0.34	20.32	2.02	18.29		0.96
Residue after 1 yr. in soil‡. ....	0.09	15.63	1.59	14.04		0.35
No. 243B: 5-20-5 granulated						
5 to 10-mesh. ....	5.00	20.31	0.22	20.09	9.86	4.96
Residue after 2 wks. in soil*. ....	0.38	18.95	1.42	17.53		1.06
Residue after 16 wks. in soil†. ....	0.31	20.50	1.95	18.54		0.96
Residue after 1 yr. in soil‡. ....	0.11	13.08	0.84	12.24		0.36
No. 243C: 5-20-5 granulated						
10 to 20 mesh. ....	5.11	20.55	0.20	20.35	9.80	4.81
Residue after 2 wks. in soil*. ....	0.40	19.65	1.52	18.13		1.22
Residue after 16 wks. in soil†. ....	0.22	20.23	1.84	18.41		1.09
Residue after 1 yr. in soil‡. ....	0.12	15.69	1.10	14.50		0.56
No. 243: 5-20-5 powdered. ....	5.18	20.93	0.73	20.20	10.43	5.01
Residue after 2 wks. in soil*. ....	0.30	18.00	1.82	16.18		0.69
Residue after 16 wks. in soil†. ....	0.27	17.67	0.74	16.93		0.84
Residue after 1 yr. in soil‡. ....	0.16	16.68	0.55	16.13		0.55
No. 244A: 5-10-5 granulated						
4 to 5-mesh. ....	5.28	10.38	0.03	10.35	4.83	5.04
Residue after 2 wks. in soil*. ....	0.21	11.60	0.62	10.98		1.12
Residue after 16 wks. in soil†. ....	0.08	12.16	0.99	11.16		1.01
Residue after 1 yr. in soil‡. ....	0.09	12.82	2.08	10.74		0.22
No. 244B: 5-10-5 granulated						
5 to 10-mesh. ....	4.92	10.45	0.03	10.42	4.58	5.11
Residue after 2 wks. in soil*. ....	0.20	9.90	0.62	9.28		0.80
Residue after 14 wks. in soil‡. ....	0.09	11.26	1.53	9.73		0.16
Residue after 16 wks. in soil†. ....	0.07	11.49	0.84	10.64		0.80
Residue after 1 yr. in soil‡. ....	0.10	10.77	1.66	9.11		0.23
No. 244C: 5-10-5 granulated						
10 to 20-mesh. ....	5.30	10.60	0.05	10.55	4.60	5.25
Residue after 2 wks. in soil*. ....	0.21	10.13	0.68	9.45		0.88
Residue after 16 wks. in soil†. ....	0.08	11.27	0.54	10.73		0.60
Residue after 1 yr. in soil‡. ....	0.10	9.64	1.34	8.30		0.20
No. 244: 5-10-5 powdered. ....	5.10	10.66	0.08	10.58	4.93	5.17
Residue after 2 wks. in soil*. ....	0.20	8.63	0.44	8.19		0.62
Residue after 16 wks. in soil†. ....	0.12	8.75	0.11	8.64		0.40
Residue after 1 yr. in soil‡. ....	0.10	8.14	0.10	8.04		0.28
No. 245A: 5-10-5 granulated						
4 to 5-mesh. ....	5.06	10.57	0.07	10.50	5.78	5.67
Residue after 2 wks. in soil*. ....	1.22	10.15	1.42	8.73		1.86
Residue after 16 wks. in soil†. ....	0.65	11.37	2.29	9.09		0.87
Residue after 1 yr. in soil‡. ....	0.77	12.67	2.81	9.86		0.25

\*Fertilizer placed in cheesecloth in the soil.

†Fertilizer in direct contact with soil.

‡Fertilizer placed in Monel metal wire cloth in the soil.

§Samples lost.

TABLE 2.—Continued.

Material	N, %	Total P <sub>2</sub> O <sub>5</sub> , %	Insol. P <sub>2</sub> O <sub>5</sub> , %	Avail. P <sub>2</sub> O <sub>5</sub> , %	Water- sol. P <sub>2</sub> O <sub>5</sub> , %	K <sub>2</sub> O, %
No. 245B: 5-10-5 granulated						
5 to 10-mesh.....	4.82	10.66	0.04	10.62	5.42	5.48
Residue after 2 wks. in soil*....	1.17	9.68	—§	—§		1.90
Residue after 14 wks. in soil†...	0.57	10.18	0.90	9.28		0.40
Residue after 16 wks. in soil†...	0.64	9.95	1.21	8.74		1.27
Residue after 1 yr. in soil†.....	0.69	10.47	1.33	9.14		0.27
No. 245C: 5-10-5 granulated						
10 to 20-mesh.....	5.02	10.45	0.06	10.39	5.45	5.31
Residue after 2 wks. in soil*....	1.01	8.75	—§	—§		0.96
Residue after 16 wks. in soil†...	0.71	10.18	1.17	9.02		0.61
Residue after 1 yr. in soil†.....	0.70	8.72	1.16	7.56		0.21
No. 245: 5-10-5 powdered.....	5.25	10.60	0.05	10.55	5.98	5.70
Residue after 2 wks. in soil*....	1.04	9.43	—§	—§		—§
Residue after 16 wks. in soil†...	0.67	10.22	0.48	9.74		0.43
Residue after 1 yr. in soil†.....	0.65	10.11	0.44	9.67		0.33

\*Fertilizer placed in cheesecloth in the soil.

†Fertilizer placed in Monel metal wire cloth in the soil.

‡Fertilizer in direct contact with soil.

§Samples lost.

The analyses of these two fertilizers are especially significant and yield considerable information regarding the solubility of these fertilizer ingredients and the changes that take place in the granular fertilizers after they have been mixed with the soil.

Considering first fertilizer No. 244B in which all of the nitrogen was in inorganic form, practically all of the nitrogen soon dissolved out of the fertilizer granule. This fertilizer which originally contained 4.92% of nitrogen showed only 0.09% nitrogen after being mixed with the soil 14 weeks. On the other hand, fertilizer No. 245B in which 25% of the nitrogen was in organic form showed a much less rapid loss of nitrogen. Originally this fertilizer contained 4.82% nitrogen and after being mixed with the soil 14 weeks the fertilizer granules still contained 0.57% of nitrogen.

The percentage of available phosphoric acid<sup>6</sup> remaining in these granulated fertilizers after they had been mixed with the soil was remarkably high when it is considered that this Ontario loam soil has a high capacity for phosphorus fixation. These fertilizers that originally contained 10.42% and 10.62% available P<sub>2</sub>O<sub>5</sub> still contained 9.73% and 9.28% available P<sub>2</sub>O<sub>5</sub>, respectively, after the granules had been mixed with the soil for 14 weeks. The percentage of insoluble P<sub>2</sub>O<sub>5</sub> in these fertilizers increased considerably after they were mixed with the soil. Originally they contained only 0.03% and 0.04% insoluble P<sub>2</sub>O<sub>5</sub> but after being mixed in the soil 14 weeks these percentages had increased to 1.53% and 0.90%, respectively. This increase in *percentage* of insoluble P<sub>2</sub>O<sub>5</sub> was probably due to two causes. First,

<sup>6</sup>As determined by the neutral ammonium citrate method of the A. O. A. C.

the loss of the soluble ingredients of the fertilizer granules would of itself increase the percentage of insoluble material remaining. Secondly, reversion of the soluble  $P_2O_5$  by reaction with the soil would also increase the total amount and percentage of insoluble  $P_2O_5$ . To the authors it seemed particularly noteworthy that there was such a large percentage of available  $P_2O_5$  remaining in the fertilizer granules after they had been mixed with soil in the field for 14 weeks.

Since the potash in fertilizers is required by law to be water-soluble, it is to be expected that the potash would dissolve out of the fertilizer granules soon after they had been mixed with the soil. Analyses of the fertilizer residues recovered from the soil showed that the potash had dissolved out of the fertilizer granules quite rapidly. Originally fertilizer No. 244B contained 5.11%  $K_2O$  (Table 2), but after being mixed with soil in the field for 14 weeks there was only 0.16%  $K_2O$  remaining in the fertilizer granules. The potash did not dissolve out so rapidly when the fertilizer was placed in concentrated bands between Monel metal cloth and buried in the soil. In this case 0.8%  $K_2O$  remained in the fertilizer residue after it had been in the soil for 16 weeks.

Analyses of fertilizer 245B showed similar results with the potash. Originally this fertilizer contained 5.48%  $K_2O$  and after it had been mixed in intimate contact with the soil for 14 weeks only 0.4%  $K_2O$  remained in the residue of the fertilizer granules. Where this fertilizer had been placed in bands between Monel metal wire cloth in the soil for 16 weeks, however, there was 1.27%  $K_2O$  still remaining in the fertilizer residue. Tests have shown that there is a rapid rate of fixation of potash in this soil and apparently this rate of fixation was retarded by placing the fertilizer in bands between the metal cloth.

Aside from the significant difference in the rate of fixation of potash just discussed, there was a rather close similarity in the analyses of the residue of fertilizer 244B where it was mixed with the soil for 14 weeks and then the granules recovered as compared with the same fertilizer placed in bands between Monel metal wire cloth, buried in the soil 16 weeks, and then recovered for analysis. Similarly, with fertilizer No. 245B, there was a close correlation between the analysis of the fertilizer residue that had been mixed with the soil and that that had been placed in the metal cloth in the soil. Since each of these fertilizers showed this close correlation, it seems reasonable to expect that the analyses (Table 2) of the residues of each of the fertilizers that had been placed between the Monel metal wire cloth buried in the soil would give a rather close approximation of the changes that occur in fertilizers when they are mixed with the soil. It is probable, however, that with the powdered or more finely divided fertilizers there would be a more rapid rate of fixation of phosphoric acid and of potash when these were mixed through the soil than where they were placed in concentrated bands between metal cloth buried in the soil. Judging from the correlation in the analyses of fertilizers 244B and 245B, it seems probable that the analyses (Table 2) of the fertilizers recovered from the metal bands are a close approximation of the changes that take place in the soil when fertilizers are applied in band applications in field practice.

From the analyses of fertilizers No. 243 and 244 in which the nitrogen was wholly in inorganic form derived from ammonia, ammonium sulfate, and sodium nitrate, it can be seen that the inorganic nitrogen passed out of the fertilizer bands into the soil very rapidly regardless of the size of the granules (Table 2). Fertilizer No. 243 contained originally 4.88%, 5.00%, 5.11%, and 5.18% of nitrogen in the three sizes of granules and in the powdered form, respectively. Yet after only 2 weeks in the soil the percentage of nitrogen remaining in the residues of this fertilizer was 0.39, 0.38, and 0.40 in the granulated forms and only 0.30 in the powdered form. Thus it is evident that over 92% of the inorganic nitrogen passed out of the fertilizer bands into the soil within 2 weeks. The little remaining nitrogen then disappeared less rapidly as there was a very slight further loss in 16 weeks. After 1 year in the soil the amount of nitrogen remaining in the fertilizer residue was negligible, being 0.16% and less in the different samples.

Fertilizer No. 244 showed a similar rapid movement of nitrogen into the soil. Originally the different lots of this fertilizer contained 5.28%, 4.92%, 5.30%, and 5.10% of nitrogen, but after 2 weeks in the soil all of these lots showed only 0.20% and 0.21% of nitrogen remaining in the fertilizer residue. There was no appreciable difference in the rate of solution of the inorganic nitrogen from the granulated or powdered forms.

The organic nitrogen passed into the soil more slowly as shown in the analyses of fertilizer No. 245 (Table 2). In this 5-10-5 fertilizer one-fourth of the nitrogen was in organic form (cottonseed meal, Table 1). Samples of this fertilizer showed that it originally contained 5.06%, 4.82%, 5.02%, and 5.25% of total nitrogen in the three granulated sizes and in the powdered form, respectively. After being in the soil 2 weeks the residues of these fertilizers analyzed 1.22%, 1.17%, 1.01%, and 1.04% of nitrogen, respectively. Since in the other fertilizers (Nos. 243 and 244) it was found that 92% or more of inorganic nitrogen passed out of fertilizer bands into the soil within 2 weeks and since there was only about 1.25% of organic nitrogen in fertilizer No. 245 originally, it is evident that most of the organic nitrogen was still in the fertilizer residues after 2 weeks in the soil.

After 16 weeks in the soil the four samples of fertilizer No. 245 showed 0.65%, 0.64%, 0.71%, and 0.67% of nitrogen remaining in the residues of these fertilizers. This indicates that approximately half of the organic nitrogen still remained in the fertilizer bands. Apparently the organic nitrogen was retained in the larger granules slightly longer than in the powdered fertilizer as shown by the analyses after the fertilizers had been in the soil for 2 weeks. However, after 16 weeks in the soil, the amount of nitrogen remaining in the fertilizer was remarkably uniform regardless of the size of the granule as shown by the figures just quoted. After 1 year in the soil there were no additional significant changes in the percentage of nitrogen remaining in the fertilizer residues. In two cases (No. 245A and 245B, Table 2), there was a slight increase in the *percentage* of nitrogen remaining in the fertilizer residue. This was probably due to a more rapid loss of other soluble ingredients which would automatically increase the percentage of the remaining ingredients.

Potash disappeared from the fertilizer bands quite rapidly regardless of the size of the granules. The granulated fertilizers however, retained the potash a little longer than the powdered forms. Within 2 weeks 60% to 80% of the soluble potash had disappeared from the fertilizer bands in the soil, with the fertilizers containing organic nitrogen retaining the potash longer. However, less than one-fifth of the potash remained in the fertilizer bands after 16 weeks in the soil and half of this disappeared by the end of the year. For example, in fertilizer No. 243A, these large granules (4- to 5-mesh) originally contained 5.17% of potash. After 2 weeks in the soil there was only 1.00% of potash remaining in the residue of a band of this fertilizer; after 16 weeks, 0.96%; and after 1 year, 0.35%. This fertilizer in smaller sized granules (Nos. 243B and 243C, Table 2) showed a similar rapid movement of potash out of the fertilizer bands. The rate of movement of the potash was slightly more rapid from the powdered fertilizer. In this case (No. 243), the fertilizer originally contained 5.01% of potash. After 2 weeks in the soil only 0.69% of potash remained in the fertilizer residue.

The movement of potash from fertilizers Nos. 244 and 245 has already been discussed and it was shown that the potash disappeared from the fertilizer granules more rapidly where they were mixed through the soil than where the fertilizers were placed in bands between wire cloth in the soil.

Analysis of the fertilizers before they were placed in the soil showed that the water-soluble phosphoric acid was greater in the mixtures containing larger amounts of treble superphosphate (compare fertilizers No. 243 and 244, Tables 1 and 2). The 5-20-5 (No. 243) fertilizer in which 588 pounds of treble superphosphate was used per ton, contained 10.43% water-soluble phosphoric acid, or more than twice as much as the 4.93% water-soluble phosphoric acid in the 5-10-5 mixture (No. 244) in which 86 pounds of treble superphosphate were used per ton. Comparing the two 5-10-5 formulas (fertilizers Nos. 244 and No. 245) both of which contained equal amounts of treble superphosphate and also of ordinary superphosphate, it will be seen from Table 2 that No. 244, the fertilizer containing more dolomite and more ammonium sulfate and nitrate of soda but no cottonseed meal, had 4.93%, or about five-sixths as much water-soluble phosphoric acid, as the 5.98% found in the fertilizer containing more organic nitrogen and less dolomite and ammonium sulfate. With all three fertilizers it is interesting to note that the percentage of water-soluble phosphoric acid was substantially the same in the three sizes of granules as in the powdered forms. Evidently the granulating process did not affect the water solubility of the phosphoric acid. The amount of water-soluble phosphoric acid is thought by some agronomists to be an important factor in the relative value of a fertilizer in increasing crop yields.

The percentage of available phosphoric acid found in the residue of each fertilizer band was remarkably high after an entire year in the soil and there was no consistent relation between the size of the fertilizer granule and the percentage of available phosphoric acid. Before the fertilizers were placed in the soil there was no significant difference

in the percentage of available phosphoric acid nor of insoluble phosphoric acid between the powdered and granulated fertilizers of the same formula. Consequently, it would seem that the granulating process did not affect the availability of the phosphoric acid. However, in the residues of the fertilizers recovered from the soil, there was a marked increase in the percentage of insoluble phosphoric acid and this increased with the increase in size of the granules. This is evident in all three fertilizer mixtures (Table 2).

It should be noted that the fertilizers were placed in bands in the soil which would tend to prevent rapid reversion of the phosphoric acid as compared with the reaction if fertilizers had been mixed through the soil, particularly the powdered forms. Also, the metal cloth prevented intimate contact with the soil, but the fertilizers were exposed to the natural action of the soil solution. Hence, since there was a close correlation between the analyses of the two granulated fertilizers that had been mixed through the soil and the analyses of the same fertilizers recovered from the bands between Monel wire cloth placed in the soil, it is felt that the analyses reported in Table 2 give a good indication of the rates of solution of the fertilizer ingredients when fertilizers are placed in bands in direct contact with the soil.

THE PRODUCTIVITY OF ALFALFA AS RELATED TO MANAGEMENT<sup>1</sup>L. F. GRABER AND V. G. SPRAGUE<sup>2</sup>

CUTTING or pasturing the fall growth of alfalfa (*Medicago sativa*) in Wisconsin is usually quite hazardous with respect to winter survival. In 1936, the hay crop was short because of excessive summer heat and drouth, and farmers generally replenished their supplies by cutting the fall growth of alfalfa resulting from generous autumnal rainfall. This proved quite harmful in 1937 with respect to winter survival, especially where only light snows prevailed. In some instances, however, ice sheets and cold caused almost complete killing of stands, where neither fall cutting nor pasturing were practiced. In other regions, with good snow cover, late fall cutting or pasturing was not detrimental. Such responses are similar to those observed at rather frequent intervals during the past 25 years of work in the expansion of alfalfa culture in Wisconsin.

Occasionally, it is claimed that a winter cover of tall alfalfa stubble is harmful rather than helpful in maintaining the productivity of alfalfa because it may delay early spring growth by providing a longer duration of the deeper snow cover and slower rise in soil temperatures. Such retardation is usually desirable with respect to security of stand even though a delayed spring growth may present a very unfavorable visual contrast with the early vigor of alfalfa that survives without the presence of fall stubble. The prolongation of harmful sheets of ice by fall stubble is not of common occurrence, but when it occurs, it is highly disadvantageous with respect to survival.

The presence of dead stubble in the first growth of the following year, while usually not of serious consequence, may lower the quality of hay and enhance the likelihood of certain foliar diseases. For a number of years, the senior author has burned off old stubble in late winter or early spring while the soil was still frozen or before spring growth had started. This improves the quality of the hay not only because of the destruction of the old stubble, but also because in certain years it appears to reduce foliar diseases, such as the black stem disease (*Ascochyta*) and leaf spots (*Pseudopeziza*). However, such observational evidence is not sufficient to warrant a general recommendation of a practice which would involve fire hazards, which might amplify subsequent heaving, and which might result in previous winter injury being attributed to it. It is merely mentioned here to call attention to the objectionable features of fall stubble since the value of autumnal growth, and the winter cover it provides, is amply supported by field observations in Wisconsin and by the experimental evidence presented in this paper.

<sup>1</sup>Contribution No. 124 from the Department of Agronomy, University of Wisconsin, Madison, Wis. Published with the approval of the Director of the Wisconsin Agricultural Experiment Station. Received for publication October 22, 1937.

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In 1931 a series of cutting trials were begun to measure the effect of fall removals of top growth and also early cutting of the first growth on the productivity of hardy Canadian variegated alfalfa. Late winter or early spring burning of winter cover was not used to eliminate the stubble in these trials. It was hoped, at the time the trials were begun, that winter conditions might not be so differential as to cause a spontaneous and heavy loss of stand for any one unfavorable cutting treatment. Such hopes were fully realized during the following three years. In Part I of this paper only the data pertaining to the removals of fall growth of alfalfa given uniformly deferred summer cuttings will be presented. In Part II, the responses from early cutting of the first growth will be discussed in their relation to leaf-hopper injury, fall cutting treatments, and fertility levels.

### I. REMOVALS OF FALL GROWTH CUTTING TREATMENTS

The productivity of alfalfa was measured at two levels of fertility in field trials on the University Farm at Madison, Wisconsin. A well-established, thick, and uniform stand of Canadian variegated alfalfa, sown June 27, 1930, was given three cutting treatments during 1931, 1932, and 1933 as follows: (A) Two deferred (near full bloom) summer cuttings and no fall cutting; (B) two deferred (near full bloom) summer cuttings and one late fall cutting; and (C) two deferred (near full bloom) summer cuttings, one early fall and one late fall cutting.

In 1934, only two uniformly deferred summer cuttings were taken. All the above cutting treatments provided full opportunity for storage of reserve foods during the summer period and for the elimination of noteworthy injury from leaf-hoppers (*Empoasca fabae*). Treatment A provided for maximum fall storage and abundant winter cover. Treatment B provided for maximum fall storage, but the winter cover was nearly all removed after growth had ceased in late October or early November. Only about 1½ inches of the basal uncut portions of the stems remained after cutting and harvest. Treatment C was planned to reduce food storage by cutting during the middle of the fall storage period (late September and early October) when not only was photosynthesis and storage interrupted, but reserves were subsequently utilized for new fall growth. This new fall growth was removed in late October or early November on the same dates and in the same manner as for fall cutting treatment B. In treatment C, the opportunity for fall storage was greatly reduced, fall hardening of the overwintering parts was retarded and vegetative cover was nearly all eliminated. All cuttings were made with a field mower with the bar set about 1½ inches above the soil surface and the cut alfalfa was removed from the plats in all cases.

These trials (A, B, and C) were conducted on alternate halves of long, narrow, quadruplicated plats with limited randomization. They were 1/70 and 1/100 acre in size. The remaining halves received an early summer cutting treatment (AA, BB, and CC) the results of which are reported in part II of this paper. Borders were removed and green weights of the remaining forage were taken shortly after cutting. These were reduced to oven-dried weights of alfalfa hay by moisture determinations on representative samples. Where they appeared of any consequence, weeds and old stubble appearing in the hay were deducted from the gross yields. Such determinations of yields of oven-dried weed-free hay are reported in Table 3 and are shown graphically in Figs. 1 and 2.



## TWO LEVELS OF FERTILITY

Two fertility levels were provided by fertilization and by selection of plats where the fertility responses had been measured previously by field trials with alfalfa. Where fertilization was necessary to raise the fertility level, 20% superphosphate was applied at the rate of 800 pounds per acre and muriate of potash (50%  $K_2O$ ) at the rate of 300 pounds per acre. These applications were made in April, 1930, and were incorporated into the surface 3 inches of soil by cultivations prior to the seeding which was done on June 27, 1930. For convenience

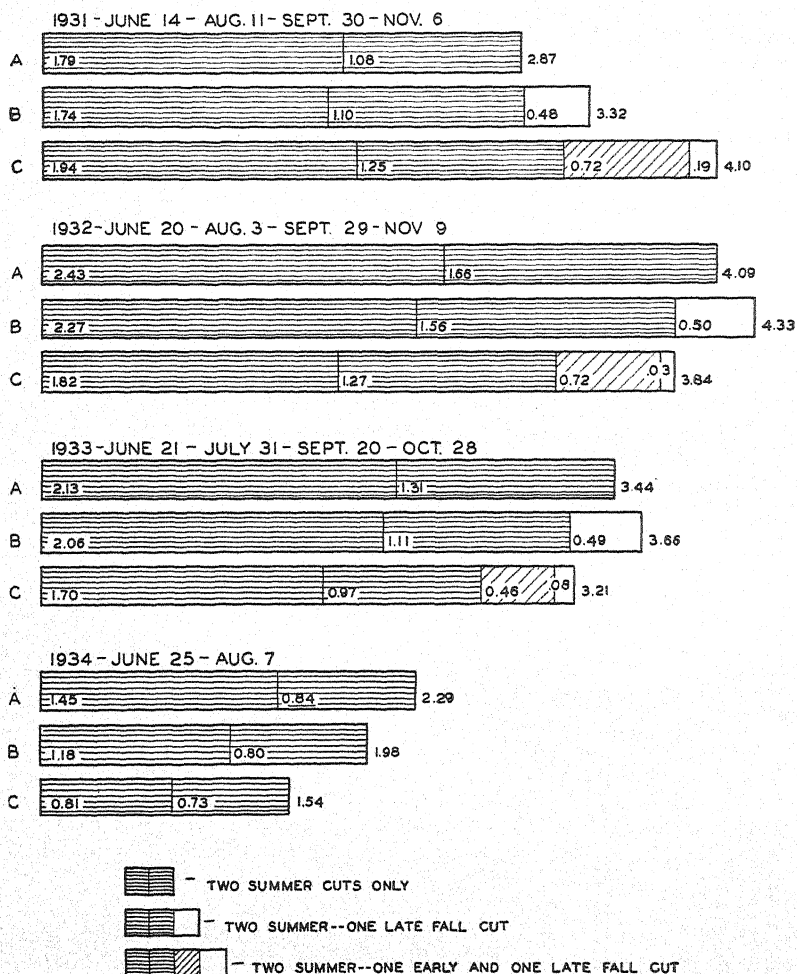


FIG. 1.—Two deferred summer cuttings with three fall cutting treatments of alfalfa grown on soil of optimum fertility.

(Yields in tons per acre of oven-dried, weed-free hay.)

in expression the two levels of fertility are referred to as optimum and moderately low.

Randomized samplings of soil (Miami silt loam) in each plat were taken by Prof. E. J. Graul of the Soils Department of the University of Wisconsin and were analyzed in February, 1933, for available phosphorus ( $P_2O_5$ ) and potash ( $K_2O$ ) and for acidity. The results are shown in Table 1.

The surface soil in each plat showed a medium minus degree of acidity—about pH 5.8. No lime was applied prior to or during the course of these trials. The areas had provided from fair to good yields of alfalfa hay in accordance with fertility variations for 6 years previous to this trial. The topography of this experimental area was fairly level, although there was sufficient slope to provide for moderately good surface runoff of excess moisture. The plats high in fertility had a little higher elevation and slightly better surface drainage.

#### WEATHER CONDITIONS

Since alfalfa has a very high water requirement and yields are much dependent on moisture supply, the regional rainfall which occurred during the five growing seasons is given in Table 2 as taken from the records of the U. S. Weather Bureau located about  $2\frac{1}{2}$  miles from the experimental plats.

TABLE 1.—Pounds of available  $P_2O_5$  and  $K_2O$  per acre in the surface 6 inches of soil on which alfalfa was grown with various cutting treatments.

Treatment, 4 plats averaged	$P_2O_5$ , lbs.	$K_2O$ , lbs.
Optimum Level of Fertility		
A and AA.....	41	198
B and BB.....	30	154
C and CC.....	40	194
Moderately Low Level of Fertility		
A and AA.....	25	103
B and BB.....	23	103
C and CC.....	26	127

TABLE 2.—Rainfall in inches at Madison, Wisconsin.

Month	1930	1931	1932	1933	1934
April.....	2.95	1.97	1.04	3.75	1.08
May.....	4.23	1.74	3.67	9.35	0.82
June.....	6.60	3.05	3.15	1.64	2.77
July.....	2.84	2.10	4.06	3.33	3.42
August.....	1.58	5.19	2.51	2.57	2.21
September.....	4.79	7.17	0.18	3.58	4.25
October.....	1.63	3.11	3.68	1.48	2.27
Total.....	24.62	24.33	18.29	25.70	16.82

The year the alfalfa plats were seeded (1930) was one of abundant and well-distributed rainfall from April to October, inclusive, and very good uniform stands were obtained. The alfalfa was not cut that season. The moderate deficiency in rainfall during April and May,

1931, was amply offset by the abundant reserves of subsoil moisture from 1930. Only in the year of 1934 was it extremely hot and dry from April to August and this is reflected in the seasonal yields of alfalfa hay. Fortunately no severe winter conditions prevailed that would seriously injure well-managed hardy alfalfa. In general, however, the winters of 1930, 1931, 1932, and 1933 were sufficiently adverse to

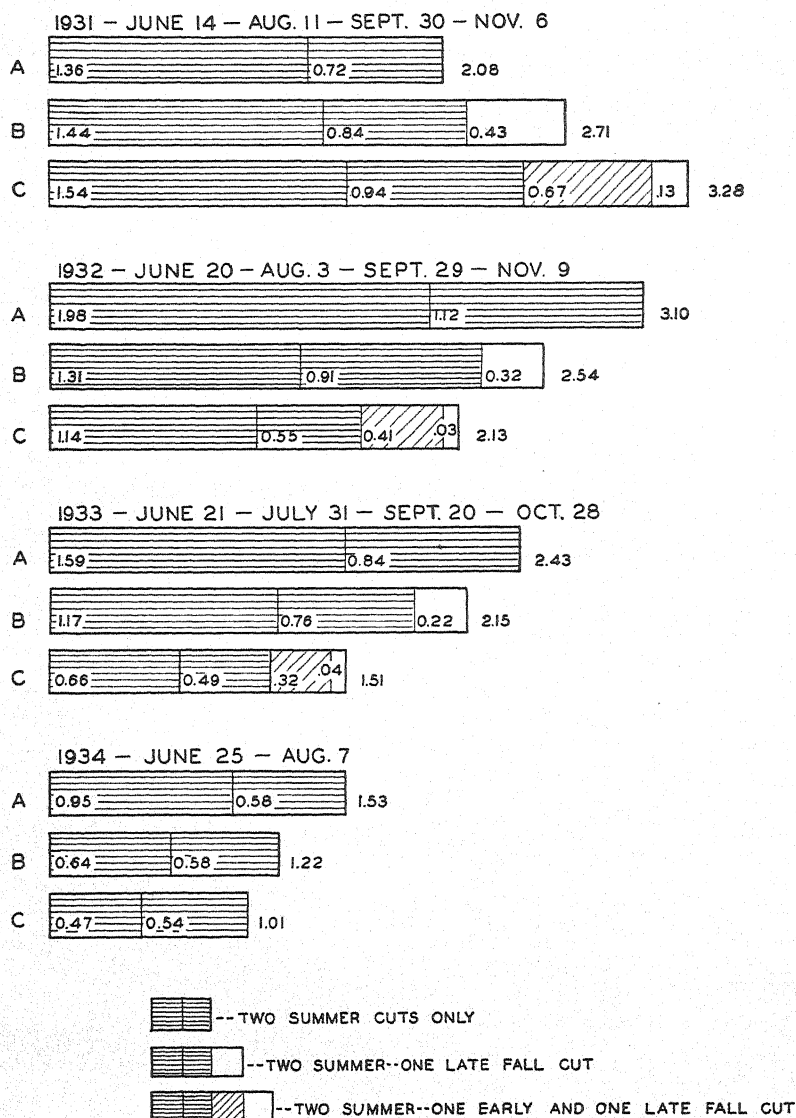


FIG. 2.—Two deferred summer cuttings with three fall cutting treatments of alfalfa grown on soil moderately low in fertility.

(Yields are in tons of oven-dried, weed-free hay.)

reflect considerable loss of alfalfa given unfavorable management for winter survival and subsequent productivity.

#### FALL CUTTING LOWERS PRODUCTIVITY

Fall cuttings reduced subsequent yields (Figs. 1 and 2) particularly when both food storage was reduced and fall cover removed (treatment C). A precise measure of the residual effects of 3 years (1931, 1932, and 1933) of the fall cutting treatments B and C compared with no fall cutting, treatment A, is reflected in the yields of the two annual and uniformly deferred summer cuttings of 1932, 1933, and 1934. These are given in Table 3. It will be noted that with the optimum level of fertility, one late fall cutting annually (B) for 3 years reduced the total subsequent summer yields for 3 years by a total of only 0.84 ton per acre, or 8.5%, whereas two fall cuts (C) resulted in 2.52 tons less hay, or a loss of 25.7%. Where the soil was moderately

TABLE 3.—*The influence of fall cutting treatments in 1931, 1932, and 1933 on the productivity of alfalfa with early and deferred cuttings of the first crop in 1932 and 1933, expressed in yields of oven-dried, weed-free alfalfa hay in tons per acre.*

Cutting treatment	Yields from two summer cuts in 1932, 1933, and 1934			Total yields, 1931-34, incl.			Total yields, 1934	
	Total	Loss		All summer cuts	All fall cuts	All cuts	Two cuts	% increase with optimum fertility
		Tons	%					
Optimum Fertility								
A	9.82	—	—	12.69	—	12.69	2.29	49.6
B	8.98	0.84	8.5	11.82	1.47	13.29	1.98	62.3
C	7.30	2.52	25.7	10.49	2.20	12.69	1.54	52.4
Moderately Low Fertility								
A	7.06	—	—	9.14	—	9.14	1.53	—
B	5.37	1.69	23.9	7.65	0.97	8.62	1.22	—
C	3.85	3.21	45.5	6.33	1.60	7.93	1.01	—
Optimum Fertility								
AA	7.27	—	—	10.14	—	10.14	1.69	42.0
BB	5.81	1.46	20.1	8.66	1.07	9.73	1.27	84.0
CC	4.21	3.06	42.1	7.39	1.68	9.07	0.93	55.0
Moderately Low Fertility								
AA	5.73	—	—	7.81	—	7.81	1.19	—
BB	3.32	2.41	42.0	5.59	0.78	6.37	0.69	—
CC	2.15	3.58	62.5	4.63	1.35	5.98	0.60	—

low in fertility the losses in summer productivity were much greater, treatment B reducing the subsequent summer tonnage 23.9%, or 1.69 tons, and treatment C, 45.5%, or 3.21 tons, compared with A in which fall cutting was not practiced.

The total yields of the two summer cuttings (treatment A) and the summer and fall cuttings of treatments B and C for the 3 years (1931, 1932, and 1933) in which fall cuttings were made, were 10.4, 11.31, and 11.15 tons, respectively. The total yields from treatments B and C were slightly larger (8.7% and 7.2%) than those obtained from treatment A where the fall growth was not a part of the total yields, being allowed to remain as winter cover. This comparison applies to soil with the optimum level of fertility. With alfalfa growing on soil moderately low in fertility such yields were 7.61 tons for A, 7.40 tons for B, and 6.92 tons for treatment C. These yields were slightly lower (2.7% and 9.0%) with cuttings of the fall growth than without.

The total yields during the 4-year period (1931-34) for all cuts of treatments A, B, and C (both summer and fall cuttings in case of B and C) did not vary widely when the fertility level was optimum (Table 3), but with moderately low fertility treatment C produced 1.21 tons, or 13.2%, less than A and B produced 0.52 ton, or 5.7%, less than A for the 4-year period.

Fertility levels had the greatest influence on the productivity of alfalfa as measured by total yields over the 4-year period. With a moderately low level of fertility, cutting treatment A produced 3.55 tons, or 28%, less hay; B, 4.67 tons, or 35.1%, less; and C, 4.76 tons, or 37.5%, less than the total yields obtained from the comparable series on the soil of optimum fertility.

The yield data from the two deferred summer cuttings and the total yields clearly demonstrate that alfalfa growing under very favorable soil conditions with respect to fertility and surface drainage is more likely to maintain productivity under adverse fall cutting treatments.

#### SUMMARY ON EFFECT OF FALL CUTTINGS

The autumnal growth of alfalfa provides for food storage in and hardening of the over-wintering parts of alfalfa and for winter cover in the form of stubble which are important factors in the effective winter survival and subsequent productivity of alfalfa in Wisconsin. A comparison was made of such a favorable over-wintering condition in hardy Canadian variegated alfalfa with one where the fall growth was removed by cutting late and thus not reducing autumnal storage, but eliminating most of the vegetative cover and with one where autumnal food storage was reduced and the stubble cover was removed by two fall cuttings.

Removal of vegetative cover in late autumn for 3 years without reducing fall storage of reserve foods (very late fall cutting) lowered the productivity of alfalfa as measured by two deferred cuttings in three subsequent and consecutive summers, 8.5% on soil of optimum fertility and 25.7% on soil moderately low in fertility.

Elimination of vegetative cover and the lowering of fall storage of food (midfall and late fall cutting) for 3 years reduced the summer

productivity of alfalfa in three subsequent and consecutive summers 23.9% on the soil of optimum fertility and 45.5% on the soil moderately low in fertility.

While abundant stubble cover may, at times, be objectionable because the presence of old alfalfa in the first growth of the following year may lower somewhat the quality of hay, increase foliar diseases, and retard early spring growth, the benefits in terms of subsequent productivity and duration from such winter cover, including concomitant maximum autumnal storage of food and winter hardening, overcome, to a large degree, such disadvantages.

When the utilization of the fall growth of alfalfa becomes a necessity, cutting or pasturing in late autumn after food storage has occurred would seem much less harmful with respect to survival and subsequent productivity than earlier removals of fall growth.

Alfalfa withstands unfavorable fall cutting treatments much more effectively when grown with an optimum level of soil fertility and good surface drainage.

## PART II. EARLY VS. DEFERRED CUTTING OF THE FIRST GROWTH OF ALFALFA

The time and frequency of cutting alfalfa are influenced by so many variable factors, such as moisture supply, soil conditions, length of the growing season, intensity and duration of solar radiation, severity of the winter seasons, snow covering, etc., that regional cutting schedules differ very widely. An insect, the leafhopper (*Empoasca fabae*), has a direct bearing on the time of cutting the first crop in Wisconsin. Under field conditions in this state, leafhoppers rarely cause serious injury to the first growth or the fall growth of alfalfa, but if the adults lay eggs in the young second growth, severe damage may occur from large populations of resulting nymphs.

Graber and Sprague<sup>3</sup> have shown that with early cutting in June leafhoppers stunted and yellowed the second growth of alfalfa, whereas in adjacent areas where the first cutting was deferred for 12 days, injury by these insects was effectively controlled. They found a 28-fold increase in the populations of leafhopper nymphs in the second growth (July) of alfalfa in 24 plats cut on June 9, 1933, compared with 24 adjacent and alternating plats cut 12 days later on June 21, 1933. With such deferred cutting, the adults completed egg-laying in the first growth and died and the eggs were removed in the hay, thus reducing infestations of the following growth. With earlier cutting of the first growth, egg deposition not being completed was continued in the succeeding growth of young alfalfa, resulting in large numbers of nymphs which hatched in July and caused severe stunting and yellowing of the second growth. Such findings were made on the series of plats described in parts I and II.

<sup>3</sup>GRABER, L. F., and SPRAGUE, V. G. Cutting treatments of alfalfa in relation to infestations of leafhoppers. *Ecology*, 14:48-59. 1935.

## CUTTING SCHEDULES

The remaining alternate halves of the plats (1/70 to 1/100 acre) of Canadian variegated alfalfa described under treatments A, B, and C in part I of this paper were used for the early summer cutting treatments and were designated AA, BB, and CC. The dates of each cutting of treatments A, B, and C and AA, BB, and CC are given in Table 4. In 1931 and 1934 the cutting dates for A, B, and C are the same as for AA, BB, and CC, respectively. The only difference in dates of cutting of these two series occurs with the first growth of 1932 and 1933. With A, B, and C it was deferred to June 20, 1932, and June 21, 1933, when near the full bloom stage as described in part I. With AA, BB, and CC it occurred 12 days earlier, on June 8, 1932, and June 9, 1933, when the alfalfa was approximately in the tenth bloom stage.

TABLE 4.—*Cutting schedules of Canadian variegated alfalfa sown June 27, 1930, on soil of optimum fertility and soil moderately low in fertility.*

Cutting treatments		Cutting dates			
Fall	Summer (first cut)	1931*	1932	1933	1934
A	Deferred	June 14-Aug. 11	June 20-Aug. 3	June 21-July 31	June 25-Aug. 7
AA	Early	June 14-Aug. 11	June 8-Aug. 3	June 9-July 31	June 25-Aug. 7
B	Deferred	June 14-Aug. 11-Nov. 6	June 20-Aug. 3-Nov. 9	June 21-July 31-Oct. 28	June 25-Aug. 7
BB	Early	June 14-Aug. 11-Nov. 6	June 8-Aug. 3-Nov. 9	June 9-July 31-Oct. 28	June 25-Aug. 7
C	Deferred	June 14-Aug. 11-Sept. 30-Nov. 6	June 20-Aug. 3-Sept. 29-Nov. 9	June 21-July 21-Sept. 20-Oct. 28	June 25-Aug. 7
CC	Early	June 14-Aug. 11-Sept. 30-Nov. 6	June 8-Aug. 3-Sept. 29-Nov. 9	June 9-July 31-Sept. 20-Oct. 28	June 25-Aug. 7

\*Because of dry hot weather in May and early June, 1931, alfalfa was well blossomed on June 14 when the first cutting of all plats was taken.

In this discussion we are primarily concerned with the effect of 2 years of such early summer cutting of the first growth on the immediate and subsequent productivity when their influence is imposed on alfalfa given three fall cutting treatments and on alfalfa grown under conditions of optimum and moderately low soil fertility. The results are portrayed graphically in Figs. 1, 2, 3, and 4 and in Tables 3 and 5.

WINTER INJURY INDUCED BY FALL CUTTINGS INTENSIFIES  
IMMEDIATE LOSSES FROM EARLY CUTTING OF FIRST GROWTH

A matter of 12 days earlier cutting of the first growth of alfalfa in 1932 and 1933 reduced the immediate productivity of the first growth (Table 5) below that of deferred cutting from 12.3% to 28.9% (0.56





to 1.02 tons per acre) where the fertility level was optimum and from 6.4% to 38.3% (0.23 to 0.69 ton per acre) where the soil was moderately low in fertility. In southern Wisconsin, blossoming of alfalfa generally begins in the forepart of June, and with a favorable environment, the accumulations of dry weight are most rapid in the following two or three weeks.

Such was the definite trend of the yields in this trial, but it is particularly significant that the greatest losses of immediate productivity

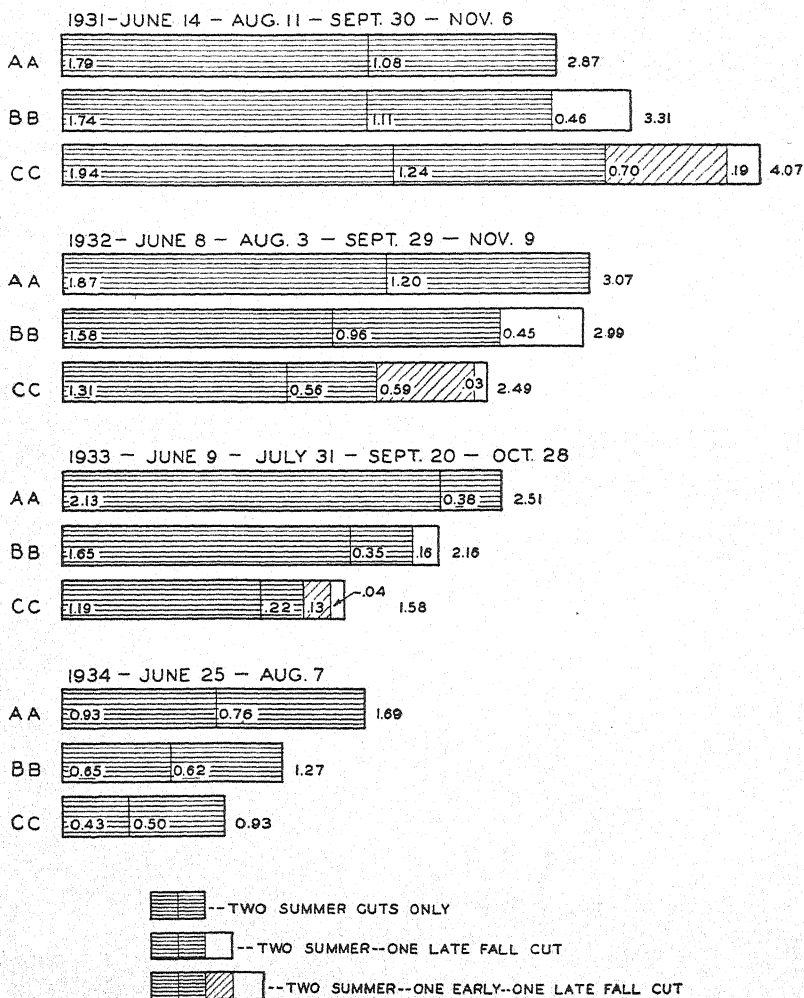


FIG. 3.—Early cutting of first growth and deferred cutting of the second growth with three fall cutting treatments of alfalfa grown on soil with optimum fertility.

(Yields in tons per acre of oven-dried, weed-free hay.)

from early cutting of the first growth in both tonnage and percentage prevailed with the alfalfa having had reduced winter cover (B and BB) and especially when not only had vegetative cover been reduced but also autumnal food storage (C and CC) of the roots. Such fall cutting treatments resulted in winter injuries which weakened and

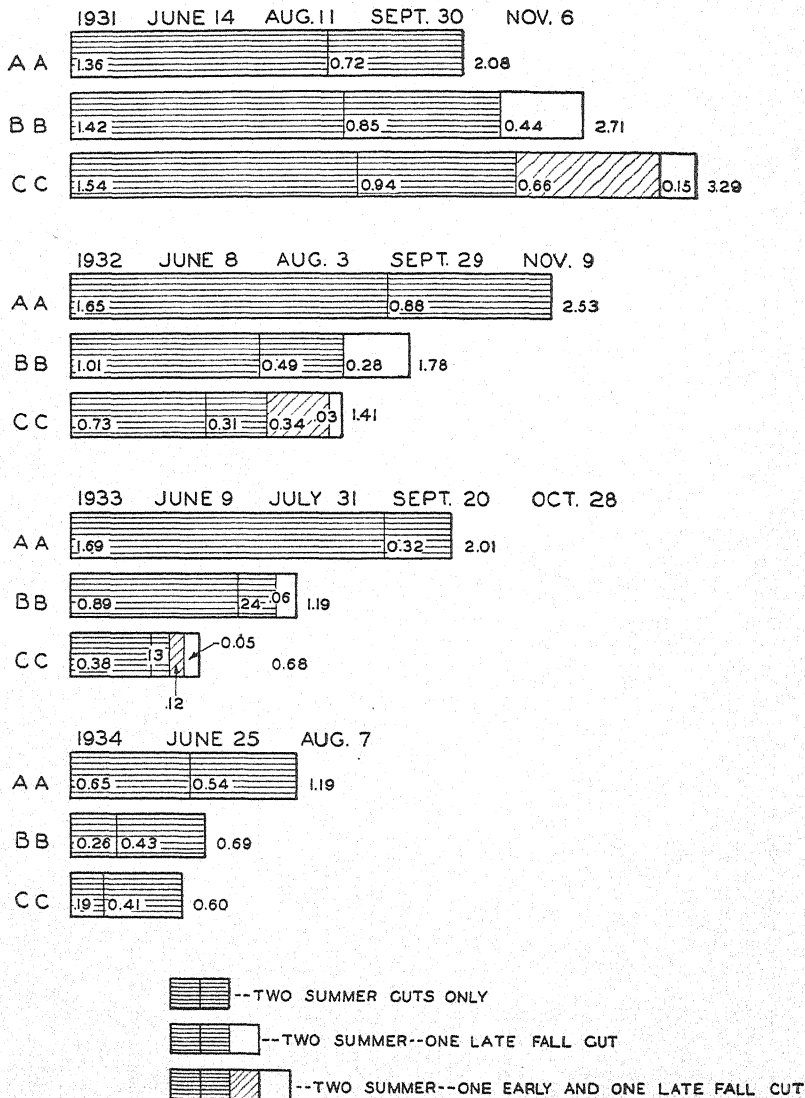


FIG. 4.—Early cutting of the first growth and deferred cutting of the second growth with three fall cutting treatments of alfalfa grown on soil moderately low in fertility.

(Yields in tons per acre of oven-dried, weed-free hay.)

retarded the succeeding growth, a condition reflected in greatly reduced yields from early cutting of the first growth.

Such findings and those relating to the productivity of the second cutting, lend great emphasis to the validity of the previous work of the senior author (Wis. Agr. Exp. Sta. Bul. 388, pp. 28-29) in which the prolongation of photosynthesis and the resultant food storage that prevails with deferred cutting of the first growth was found to be highly essential for rebuilding new root and crown tissue to replace winter-injured parts and structures.

#### LEAFHOPPERS INJURE SECOND GROWTH WHERE FIRST CROP WAS CUT EARLY

As is generally true with alfalfa cut for hay in Wisconsin, only the second growth was severely injured by leafhoppers in this trial. While such injury was unusually serious in 1932 and 1933 (not in 1931 or 1934), it prevailed, almost entirely in the 24 plats where the first growth had been cut 12 days earlier than the 24 adjacently alternating and comparable plats which were given deferred cutting of the first growth. In July 1932 and 1933 the plats of stunted and yellowed second-growth alfalfa, heavily infested with wingless leafhopper nymphs, were in sharp contrast to the adjacent plats of healthy second-growth alfalfa which remained relatively free from leafhopper infestations until just before the cutting stage. Then the nymphs in the infested plats had become winged adults and migrated to the healthy alfalfa. The injury from such migrations was primarily that of yellowing. Stunting was not particularly serious, since the alfalfa had already reached the cutting stage and was cut shortly after the yellowing occurred.

The productivity of the second growth (Table 5) of alfalfa in 1932 and 1933 on soil of optimum fertility was reduced from 46.8% to 65.1% (1.39 to 1.46 tons per acre) and on soil of moderately low fertility from 38.8% to 57.7% (0.76 to 0.60 ton per acre) with early cutting of the first crop. These were heavy losses and were due, primarily, to leafhopper injury. However, where alfalfa had suffered winter injuries induced by previous fall cutting treatments (BB and CC), the losses were greater on a percentage basis, indicating that early cutting of winter-weakened alfalfa would have reduced the yields of the second growth somewhat whether leafhoppers were present or not.

The magnitude of the losses in productivity of both first and second growths of alfalfa from early cutting of the first growth is also shown in Table 5. For the two years, 1932 and 1933, such losses varied from 1.95 to 2.48 tons per acre (25.9% to 43.0%) with alfalfa grown on soil of optimum fertility and from 0.99 to 1.29 tons (17.9% to 45.4%) on soil moderately low in fertility. In all cases, the percentage and tonnage reductions in yield from early cutting as compared with deferred cutting of the first growth were much larger (Tables 3 and 5) where alfalfa had suffered winter injuries induced by previous fall cutting treatments. These results are indicative of the hazards which prevail when the first growth of winter-weakened alfalfa is cut before the

plants have had sufficient opportunity to repair the injuries they have sustained and especially, in years when leafhoppers are abundant, as is often the case in Wisconsin.

It is recognized that with small experimental plats, the concentrations of leafhoppers may well have been much greater than would have prevailed in a similar comparison of early and deferred cutting on a large field scale, although with differential cutting of large fields of alfalfa in Wisconsin very severe injury in early cut portions of such fields has been observed. However, such damage was generally most intense at the line of juncture between the early and deferred cutting of the first crop.

#### RESIDUAL EFFECTS IN 1934

In 1934, all plats were given two uniformly deferred summer cuttings. The first cutting was taken June 25 and the second on August 7. It was a dry hot summer, and while the yields were low, they still expressed a residual influence of the cutting treatments of 1931, 1932, and 1933. With alfalfa growing on soil of optimum fertility, early cutting of the first crop in 1932 and 1933 reduced the yields (Table 5) in 1934 by 0.6 ton, or 26.2%, in case of cutting treatment AA; 0.71 ton, or 35.8%, in case of treatment BB; and 0.61 ton, or 39.6%, for treatment CC as compared with the deferred cutting treatments A, B, and C. Similarly, with a moderately low level of fertility, the reductions in the yields from previous early cuttings of the first growth were 0.34 ton, or 22.2%, for treatment AA; 0.53 ton, or 43.3%, for treatment BB; and 0.41 ton, or 40.6%, for treatment CC as compared with the deferred cutting treatments A, B, and C. The residual losses in 1934 from early cutting of the first growth in 1932 and 1933 are in general much higher than the losses (from 13.5% to 34.0%) sustained from removals of fall growth in 1931, 1932, and 1933.

The residual productivity (Table 5) of alfalfa with all cutting treatments was much greater in tonnage and soil with optimum fertility as compared with soil moderately low in fertility. The increases in yields (Table 3) due to greater fertility, ranged from 0.33 to 0.76 ton per acre, or from 42.0% to 84.0%.

#### SURVIVAL

Beginning in the fall of 1931, randomized counts of the surviving alfalfa plants were made in each plat and the data obtained are condensed in Table 6. As measured by counts made in 1934, the best survival prevailed in plats of high fertility where alfalfa was given deferred summer cuttings without removal of the fall growth. The most serious thinning of stand prevailed where leafhopper damage resulting from early cutting of the first growth was combined with the depressing effects of fall growth removals and moderately low fertility. The number of plants per unit area is not a fair indication of thickness of growth or of yields since with high fertility, high reserves, winter cover, and the absence of leafhopper damage, the surviving plants were more vigorous and occupied much more space. An estimate of the

condition of the stand in August, 1934, is given in the last column of Table 6.

TABLE 6.—*The effect of fall cutting treatments and early cutting of the first crop on the survival of Canadian variegated alfalfa sown June 27, 1930.*

Cutting treatments	Number of plants per square foot									Estimated condition of stand Aug. 27 1934
	1931, Nov.	1932			1933			1934		
		Apr.	May	Nov.	Apr.	July	Aug.	May	Aug.	
Optimum Fertility										
A	27	25	14	7.8	8.5	7.0	7.5	4.6	3.8	Very good
AA	—	—	—	7.3	7.3	6.5	3.0	2.7	2.3	Good—
B	36	24	12	7.7	8.0	5.0	5.6	3.1	3.4	Very good
BB	—	—	—	7.8	7.7	6.0	3.3	2.6	2.5	Fairly good
C	32	17	10	7.3	8.0	3.5	3.2	2.1	1.7	Poor+
CC	—	—	—	7.3	5.0	3.0	1.6	1.1	1.2	Poor
Moderately Low Fertility										
A	30	24	12	6.7	7.0	4.5	5.9	3.6	3.7	Good
AA	—	—	—	7.0	6.7	5.5	3.8	2.9	2.5	Fair+
B	35	16	7	5.0	5.7	3.5	3.9	2.5	1.8	Fair—
BB	—	—	—	5.3	5.3	4.0	1.9	0.8	1.0	Poor
C	34	12	6	3.3	4.0	2.1	3.1	1.6	1.6	Poor—
CC	—	—	—	3.3	2.7	1.8	1.4	0.5	0.8	Very poor

#### SUMMARY OF RESULTS FROM EARLY AND DEFERRED CUTTINGS OF FIRST GROWTH OF ALFALFA

The summer productivity of alfalfa as measured by two cuttings was greatly reduced by early cutting of the first growth. Alfalfa cut when about one tenth of the blossoms had appeared compared with that cut 12 days later when it was fairly well blossomed reduced the yields from the first cutting in 1932 and 1933 from 6.4% to 38.3% with the greatest losses prevailing with alfalfa which had suffered winter injuries because of unfavorable fall cutting treatments.

Early cutting of the first growth reduced the productivity of both the first and second cuttings. The reductions in yields of the first growth are ascribed primarily to the removal of the photosynthetic area before the accumulations of dry weight became most rapid, and such losses were most severe where previous fall cuttings had induced winter injury which retarded and weakened growth the following spring. The losses in productivity of the second crop were very pronounced (38.8% to 65.1%) and they were due, primarily, to leaf-

hopper injury which was manifested by an intense yellowing and stunting of the young top growth in all plats where the first crop had been cut early.

With all cutting treatments whether favorable or unfavorable, the immediate and residual productivity of alfalfa was markedly increased with the optimum level of soil fertility when compared with a moderately low level of soil fertility.

Fall cutting treatments, particularly when they reduced both winter cover and autumnal food storage, greatly intensified the losses from early cutting of the first growth.

The factors which depressed the productivity of alfalfa also shortened the duration of the stands.

### GENERAL SUMMARY

Alfalfa is very sensitive in its response to managerial treatment under the environmental conditions of southern Wisconsin. The total production of oven-dried, weed-free alfalfa hay during the 4-year period (1931-1934) of this trial varied from 13.29 tons to 5.98 tons per acre in accordance with management.

The productivity and duration of Canadian variegated alfalfa was compared under favorable conditions of management, including the maintenance of an optimum level of fertility, ample summer and fall storage of food reserves, abundant vegetative winter cover, and the absence of leafhopper damage, with the alternatives of moderately low fertility, early cutting of the first growth and leafhopper injury, reduced winter cover and reduced fall and summer storage of food reserves. The responses of alfalfa to various combinations of such favorable factors and unfavorable stresses were measured on the basis of productivity and survival. It was not possible to differentiate fully the degree to which each factor of management influenced the productivity or duration of the alfalfa, but their interactions could be quite clearly approximated.

Cutting treatments not only affected the immediate productivity of alfalfa but also subsequent productivity and survival. Such residual influences were very significant in this trial.

All fall cutting treatments proved harmful in this experiment, but late fall cutting after maximum food storage had occurred was definitely less detrimental with respect to productivity and survival than fall cuttings which not only reduced vegetative cover but also autumnal storage of reserve foods.

An optimum level of fertility greatly increased the productivity and duration of alfalfa when compared with that grown on soil moderately low in fertility. This held true whether the cutting treatments were favorable or unfavorable with respect to root storage, winter cover, and leafhopper damage.

Twelve days earlier cutting of the first growth in 1932 and 1933 greatly lowered the immediate and subsequent productivity and the survival of alfalfa. It depressed the productivity of the first growth, particularly, of alfalfa which had suffered winter injuries induced by previous fall cutting treatments. It resulted in very severe infestations

of leafhoppers, which caused heavy losses in the productivity of the second growth and such losses were most pronounced when alfalfa had undergone winter injury induced by previous fall cutting treatments.

The residual effects of the various cutting treatments applied to alfalfa in 1931, 1932, and 1933 were reflected, clearly and definitely, in the productivity of alfalfa in 1934.

## REACTION OF F<sub>3</sub> PROGENIES OF AN ORO × TURKEY-FLORENCE CROSS TO TWO PHYSIOLOGIC RACES OF *TILLETIA TRITICI* AND ONE OF *T. LEVIS*<sup>1</sup>

O. A. VOGEL AND C. S. HOLTON<sup>2</sup>

A MAJOR problem in the wheat-improvement program of the Pacific Northwest is the production of bunt-resistant varieties suitable for commercial use. This problem would be relatively simple were it not for the continued appearance of previously unknown physiologic races of bunt.

Oro (C. I. 8220)<sup>3</sup> and Turkey-Florence (C. I. 10080) are highly resistant to the other known races but are very susceptible to races L-8 and T-11, respectively, and both are slightly susceptible to T-8.<sup>4</sup> A cross of these two varieties of wheat might be expected to produce some segregates resistant to all the races of bunt.

### METHODS

The cross Oro × Turkey-Florence was made at the Arlington Experiment Farm, Arlington (near Washington, D. C.), Virginia, in 1932 and the F<sub>2</sub> plants were grown under irrigation at the Arizona Agricultural Experiment Station, Tuscon, Ariz., in 1934.

Seed of each of 168 F<sub>2</sub> plants was divided into three lots of 43 to 50 kernels, depending upon the number available. One lot was inoculated with L-8, one with T-11, and the third with T-8. Sufficient seed of 22 additional F<sub>2</sub> plants was available for inoculating with L-8, and 13 of these were also inoculated with T-11. The seeds were space-planted approximately 2 inches apart in 10-foot rows on October 18 and 19, 1934, at Pullman, Wash. One row of each parent was planted after each 10 rows of progeny. Plant selections from F<sub>3</sub> families were tested in 1936 for resistance to the three races individually and for resistance to a composite of 18 collections containing at least five additional races. Plant selections made from the F<sub>4</sub> families were tested in 1937 to the 19 races described by Rodenhiser and Holton.<sup>5</sup>

The percentage of bunt of each row was determined on the basis of plant counts according to the method described by Smith.<sup>6</sup>

<sup>1</sup>Cooperative investigations of the Division of Cereal Crops and Diseases and the Agricultural Experiment Station, State College of Washington, Pullman, Wash. Published as Scientific Paper No. 338, College of Agriculture and Experiment Station, State College of Washington. Received for publication October 26, 1937.

<sup>2</sup>Assistant Agronomist and Associate Pathologist, respectively. Acknowledgment is made to Dr. E. F. Gaines, Cerealist, and Mr. A. M. Schlehuber, Research Assistant, State College of Washington, Pullman, Wash., for their suggestions and cooperation.

<sup>3</sup>C. I. refers to accession number of Division of Cereal Crops and Diseases, formerly Office of Cereal Investigations.

<sup>4</sup>L-8, T-11, and T-8 are race numbers assigned by H. A. Rodenhiser and C. S. Holton in a paper entitled "Physiologic Races of *Tilletia tritici* and *T. levis*", Jour. Agr. Res., 55:483-496. 1937.

<sup>5</sup>See footnote 4.

<sup>6</sup>SMITH, W. K. Inheritance of reaction of wheat to physiologic forms of *Tilletia levis* and *T. tritici*. Jour. Agr. Res., 47:89-105. 1933.



of leafhoppers, which caused heavy losses in the productivity of the second growth and such losses were most pronounced when alfalfa had undergone winter injury induced by previous fall cutting treatments.

The residual effects of the various cutting treatments applied to alfalfa in 1931, 1932, and 1933 were reflected, clearly and definitely, in the productivity of alfalfa in 1934.

## REACTION OF $F_3$ PROGENIES OF AN ORO $\times$ TURKEY-FLORENCE CROSS TO TWO PHYSIOLOGIC RACES OF *TILLETIA TRITICI* AND ONE OF *T. LEVIS*<sup>1</sup>

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### METHODS

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Seed of each of 168  $F_2$  plants was divided into three lots of 43 to 50 kernels, depending upon the number available. One lot was inoculated with L-8, one with T-11, and the third with T-8. Sufficient seed of 22 additional  $F_2$  plants was available for inoculating with L-8, and 13 of these were also inoculated with T-11. The seeds were space-planted approximately 2 inches apart in 10-foot rows on October 18 and 19, 1934, at Pullman, Wash. One row of each parent was planted after each 10 rows of progeny. Plant selections from  $F_3$  families were tested in 1936 for resistance to the three races individually and for resistance to a composite of 18 collections containing at least five additional races. Plant selections made from the  $F_4$  families were tested in 1937 to the 19 races described by Rodenhiser and Holton.<sup>5</sup>

The percentage of bunt of each row was determined on the basis of plant counts according to the method described by Smith.<sup>6</sup>

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<sup>6</sup>SMITH, W. K. Inheritance of reaction of wheat to physiologic forms of *Tilletia levis* and *T. tritici*. Jour. Agr. Res., 47:89-105. 1933.

TABLE 1.—*Infection percentages produced by each of three races of bunt and the average percentages produced by all three races on parents and  $F_3$  lines of Oro  $\times$  Turkey-Florence.*

Progeny No.	Physiologic race			Av.	Progeny No.	Physiologic race			Av.
	L-8	T-11	T-8			L-8	T-11	T-8	
1098	5.0	0.0	0.0	1.7	1129	31.0	31.0	16.0	26
1148	11.0	0.6	0.0	3.9	1201	41.0	25.0	13.0	26
1166	7.3	4.4	0.0	3.9	1094	78.0	0.5	3.3	27
1114	10.0	0.5	2.5	4.3	1104	79.0	0.5	0.0	27
1079	4.3	15.0	5.6	8.3	1115	37.0	18.0	26.0	27
1101	23.0	0.0	3.2	8.7	1200	3.6	59.0	17.0	27
1136	34.0	0.0	0.0	11.0	1162	48.0	22.0	14.0	28
1164	30.0	1.1	1.0	11.0	1016	53.0	19.0	16.0	29
1174	4.4	24.0	5.0	11.0	1022	50.0	21.0	15.0	29
1083	38.0	1.3	0.0	13.0	1047	70.0	5.0	11.0	29
1052	7.6	26.0	7.1	14.0	1076	81.0	1.3	3.8	29
1124	42.0	0.0	0.0	14.0	1111	35.0	34.0	18.0	29
1019	12.0	26.0	7.6	15.0	1187	53.0	22.0	13.0	29
1089	45.0	0.5	0.5	15.0	1009	44.0	27.0	19.0	30
1099	16.0	26.0	3.3	15.0	1018	49.0	19.0	23.0	30
1118	45.0	0.0	0.5	15.0	1054	3.2	78.0	9.0	30
1091	7.9	35.0	4.4	16.0	1092	37.0	30.0	22.0	30
1126	16.0	21.0	11.0	16.0	1179	33.0	39.0	19.0	30
1023	18.0	31.0	1.5	17.0	1039	42.0	30.0	20.0	31
1045	26.0	14.0	9.7	17.0	1058	0.6	83.0	8.8	31
1147	47.0	1.3	2.6	17.0	1142	64.0	19.0	9.5	31
1152	49.0	0.5	2.5	17.0	1003	52.0	20.0	23.0	32
1020	17.0	17.0	20.0	18.0	1062	58.0	18.0	21.0	32
1064	7.5	37.0	9.4	18.0	1140	58	23	19	33
1086	7.0	44.0	4.2	18.0	1008	41	39	23	34
1117	17.0	18.0	18.0	18.0	1134	59	23	20	34
1125	19.0	28.0	6.4	18.0	1196	13	72	18	34
1151	53.0	0.0	1.6	18.0	1135	64	16	24	35
1161	46.0	5.4	1.2	18.0	1158	58	22	25	35
1189	51.0	3.0	0.0	18.0	1044	16	47	44	36
1190	49.0	2.7	1.4	18.0	1030	35	52	25	37
1074	23.0	18.0	17.0	19.0	1149	53	33	26	37
1107	35.0	17.0	7.0	20.0	1163	74	15	21	37
1141	58.0	0.0	0.7	20.0	1177	74	13	23	37
1172	57.0	0.5	1.1	20.0	1199	52	35	23	37
1122	61.0	1.1	1.0	21.0	1035	66	23	26	38
1123	10.0	44.0	10.0	21.0	1056	55	38	21	38
1194	6.4	46.0	10.0	21.0	1106	69	15	31	38
1051	14.0	48.0	5.0	22	1154	30	41	42	38
1066	30.0	28.0	8.9	22	1155	56	42	17	38
1082	61.0	0.0	5.9	22	1138	47	39	31	39
1150	36.0	17.0	12.0	22	1159	66	24	27	39
1004	39.0	19.0	12.0	23	1057	51	35	33	40
1063	63.0	4.4	2.9	23	1065	69	35	15	40
1105	22.0	37.0	9.3	23	1078	63	24	32	40
1130	69.0	0.0	0.0	23	1116	58	37	26	40
1176	41.0	17.0	11.0	23	1119	52	38	31	40
1087	30.0	31.0	12.0	24	1014	46	37	40	41
1103	67.0	0.0	4.1	24	1095	70	26	28	41
1128	40.0	16.0	17.0	24	1137	63	29	31	41
1010	72.0	0.0	1.5	25	1139	26	70	27	41
1067	40.0	27.0	11.0	26	1173	64	33	28	42
1127	42.0	19.0	17.0	26	1183	53	32	41	42

TABLE I.—Continued.

Progeny No.	Physiologic race			Av.	Progeny No.	Physiologic race			Av.
	L-8	T-II	T-8			L-8	T-II	T-8	
1186	68	41	17	42	1015	94	37	46	59
1034	17	86	26	43	1112	39	81	57	59
1100	77	18	34	43	1069	55	75	49	60
1182	75	23	32	43	1002	66	63	57	62
1026	63	36	33	44	1198	52.0	70.0	65	62
1038	65	27	39	44	1042	62.0	75.0	55	64
1110	36	57	39	44	1081	53.0	76.0	63	64
1167	28	62	42	44	1170	52.0	67.0	72	64
1171	56	35	41	44	1184	48.0	91.0	62	67
1197	65	29	37	44	1005	71.0	71.0	75	72
1053	69	31	35	45	1046	68.0	70.0	84	74
1075	25	83	26	45	1011	74.0	90.0	74	79
1165	46	37	51	45	1033	64.0	94.0	79	79
1029	60	47	30	46	1055	63.0	87.0	86	79
1070	79	31	28	46	1191	65.0	83.0	88	79
1059	27	84	30	47	1102	79.0	86.0	83	83
1040	83	28	32	48	1007	82.0	95.0	75	84
1188	77	36	32	48	1050	76.0	86.0	93	85
1153	75	36	37	49	1195	86.0	85.0	88	86
1185	70	38	38	49	1077	87.0	88.0	86	87
1031	36	63	50	50	1202	32.0	50.0		
1043	82	38	30	50	1203	61.0	34.0		
1093	28	86	36	50	1206	34.0	19.0		
1027	68	33	52	51	1207	56.0	66.0		
1071	37	66	49	51	1208	46.0	0.9		
1146	31	58	64	51	1209	4.7	0.0		
1028	84	34	39	52	1210	50.0	77.0		
1088	79	35	44	53	1211	53.0	35.0		
1090	86	24	49	53	1212	32.0	1.1		
1178	73	35	51	53	1213	41.0	0.6		
1006	52	58	55	55	1214	20.0	29.0		
1080	52	71	43	55	1215	44.0	35.0		
1068	55	76	36	56	1218	60.0	88.0		
1113	41	68	59	56	1219	64.0			
1131	72	32	64	56	1220	56.0			
1160	43	78	48	56	1221	19.0			
1017	55	58	59	57	1222	24.0			
1021	85	32	53	57	1223	54.0			
1032	81	40	51	57	1224	14.0			
1041	37	59	76	57	1225	77.0			
1143	42	72	60	58	1226	53.0			
1175	27	84	62	58	1227	1.3			

Par- ents	Row No.	Physiologic race			Av.	Parents	Row No.	Physiologic race			Av.
		L-8	T-II	T-8				L-8	T-II	T-8	
Oro	1145	69.0	0.0	5.7	25	Turkey-Florence	1000	3.2	50.0	12.0	22
Oro	1169	68.0	5.6	4.7	26	Turkey-Florence	1156	3.8	55.0	10.0	23
Oro	1109	72.0	5.8	3.0	27	Turkey-Florence	1180	7.9	55.0	11.0	25
Oro	1097	73.0	3.2	7.6	28	Turkey-Florence	1072	5.9	63.0	8.6	26
Oro	1025	76.0	2.3	9.7	29	Turkey-Florence	1120	2.9	64.0	11.0	26
Oro	1049	68.0	7.3	13.0	29	Turkey-Florence	1024	4.4	68.0	10.0	27

TABLE 1.—*Concluded.*

Par- ents	Row No.	Physiologic race			Av.	Parents	Row No.	Physiologic race			Av.
		L-8	T-11	T-8				L-8	T-11	T-8	
Oro	1073	73.0	5.4	10.0	26	Turkey-Florence	1036	6.9	63.0	12.0	27
Oro	1193	78.0	3.4	4.8	29	Turkey-Florence	1168	15.0	58.0	8.6	27
Oro	1133	79.0	4.3	7.1	30	Turkey-Florence	1048	6.8	65.0	18.0	30
Oro	1001	86.0	3.3	4.3	31	Turkey-Florence	1060	5.8	64.0	20.0	30
Oro	1061	78.0	4.0	10.0	31	Turkey-Florence	1096	7.2	73.0	8.9	30
Oro	1085	74.0	4.0	15.0	31	Turkey-Florence	1132	5.7	71.0	14.0	30
Oro	1181	74.0	4.8	15.0	31	Turkey-Florence	1108	5.8	78.0	10.0	31
Oro	1037	85.0	0.0	9.5	32	Turkey-Florence	1144	9.0	71.0	13.0	31
Oro	1157	85.0	6.3	12.0	34	Turkey-Florence	1012	13.0	74.0	10.0	32
Oro	1013	85.0	2.5	16.0	35	Turkey-Florence	1192	12.0	71.0	13.0	32
Oro	1121	85.0	11.0	8.1	35	Turkey-Florence	1084	10.0	81.0	8.1	33
Oro	1205	78.0	6.2	—	—	Turkey-Florence	1204	3.1	71.0	—	—
Oro	1217	66.0	0.5	—	—	Turkey-Florence	1216	8.9	61.0	—	—

## EXPERIMENTAL RESULTS

The percentage of bunt produced by each of the three races and the average percentage on each parent and progeny are recorded in Table 1. The progenies inoculated with all three races are listed in the order of the average percentage of bunt and those inoculated with less than three races are listed in the order of the row numbers.

A satisfactory genetic analysis of the results has not been made because of the lack of data for generations other than  $F_3$ , and too few  $F_3$  lines were tested in view of the number of factors that appear to be involved. The data, however, do show some results of special interest from the standpoint of breeding for resistance to races of bunt.

There were 8 of 190  $F_3$  progenies with less than 5% bunt when inoculated with L-8, 33 of 188 progenies with less than 5% when inoculated with T-11, and 33 of 168 progenies with less than 5% when inoculated with T-8. Of even more interest is the fact that 4 of 168  $F_3$  families averaged less than 5% bunt for the three races. Selections from progeny 1098 continued to be highly resistant in the  $F_4$  in 1936. In 1937 selections from these were bunt-free to 18 individual races and produced from 3 to 23% of bunted heads with L-8. The bunted heads produced by L-8 were mostly of the partially bunted type which usually contain from one to five bunt balls per head and are usually found on late tillers.

There was no correlation between the percentage of smut produced by races L-8 and T-11 in the  $F_3$  progenies ( $r = 0.0281$ ,  $P = 0.77$ ), and only a low correlation between races L-8 and T-8 ( $r = 0.4242$ ,  $P = 0.01$ ). There was, however, a rather high correlation ( $r = 0.7477$ ,  $P = 0.01$ ) between the smut produced by races T-11 and T-8.

From the standpoint of practical breeding the use of T-8 is not necessary because all progenies resistant to both L-8 and T-11 were equally resistant to T-8.

The results obtained have prompted a repetition of the study now in progress for a genetic analysis.

## SUMMARY

The reaction of the  $F_3$  progenies of Oro  $\times$  Turkey-Florence to two races of *Tilletia tritici* and one of *T. levis* was studied. Oro is susceptible to the *T. levis* race L-8; Turkey-Florence is susceptible to the *T. tritici* race T-11; and both parents are slightly susceptible to the *T. tritici* race T-8.

The factors for resistance to all three races of bunt apparently have been combined in some progenies and those for susceptibility in other progenies. Selections from progeny 1098 continued to be very highly resistant to all three races of bunt as well as to a composite of other races in the  $F_4$  and to all of the 19 individual races in the  $F_5$  generation. Selections from this progeny also appear to possess many of the desirable agronomic characteristics of both parents.

ROOT STUDIES OF FOUR VARIETIES OF SPRING WHEAT<sup>1</sup>V. C. HUBBARD<sup>2</sup>

GENERAL observations at various times have suggested that a knowledge of the root systems may do much to explain differences in drouth resistance and yield of varieties of spring wheat. Preliminary studies indicated the probable importance of hair roots (small, fibrous roots, not root hairs), and, accordingly, four varieties known to differ in productivity at Mandan and likewise presumably different in drouth resistance, were selected for detailed studies.

## MATERIALS AND METHODS

The varieties were Ceres (C.I. 6900),<sup>3</sup> Reliance (C.I. 7370), Marquis (C.I. 3641), and Hope (C.I. 8178). Their average yields at Mandan for the 5-year period 1928 to 1934 are 15.3, 15.0, 12.5, and 11.2 bushels per acre, respectively. Ceres and Reliance, on the basis of general observations and relative yields, are quite generally assumed to be more drouth resistant than the others. Hope is known to be very susceptible to high temperatures during the heading and ripening period and presumably also to drouth. All four varieties ripen at approximately the same time, except Reliance which usually matures a day or two later than the others.

Studies were made in two different years, *viz.*, 1933 and 1934. In each case the plants for study were grown in duplicate in U-shaped frames 4 feet long, 4 inches wide, and 3 feet deep buried in the ground. In the first year the frames were covered with coarse, woven wire and in the second nail-studded, removable paneled sides were used. When the plants were mature the earth surrounding the frames was removed and the latter containing the plants were lifted from the ground to facilitate washing the soil from the roots.

Uniform stands were obtained by planting thick and thinning. The plants were spaced 3 inches apart in a row and there were 16 plants per frame, or a total of 32 plants of each variety. No water was applied or other attention given throughout the growing season other than to remove occasional weeds.

Random samples of roots for study were taken from the first, second, and third foot levels. No distinction was made between seminal and adventitious roots. The root samples were preserved in small vials in diluted alcohol and the number of fibrous roots arising from each 2-cm section were counted under a 6 X magnifying glass.

The diameters of the root sections of Hope and Ceres only were determined. This was done by photographing 20 representative sections of each, enlarged to 10 times natural size, and measuring with a Starret micrometer caliper accurate to 0.001 inch. The total air-dry weights of the 192 2-cm root sections of each variety were recorded as indicative of the relative size of roots.

## EXPERIMENTAL RESULTS

The number of hair roots arising from each 2-cm section varied from 1 to 24, as many as 3 sometimes arising from a single point on

<sup>1</sup>Results of investigations conducted cooperatively by the Division of Cereal Crops and Diseases and the Division of Dry Land Agriculture, U. S. Dept. of Agriculture, at the Northern Great Plains Field Station, Mandan, N. Dak. Received for publication October 26, 1937.

<sup>2</sup>Junior Agronomist, Division of Cereal Crops and Diseases.

<sup>3</sup>C. I. refers to accession number of the Division of Cereal Crops and Diseases.

the root. There were no observable varietal differences in the latter respect though there were differences in number and size. The average number of hair roots on each 2-cm section for each of three soil levels for the four varieties are given in Table 1 and the average diameters and air-dry weights in Table 2.

TABLE 1.—*Annual and average number of hair roots on 2-cm root sections in three soil levels of four varieties of spring wheat.*

Year	No. of root sections examined in each soil level	Average number of fibrous roots arising from 2-cm root sections at			
		1 to 12 in.	13 to 24 in.	25 to 36 in.	Av. 1 to 36 in.
Ceres					
1933....	90	7.9 $\pm$ .16	6.9 $\pm$ .12	8.0 $\pm$ .13	7.6 $\pm$ .08
1934....	192	11.2 $\pm$ .14	10.0 $\pm$ .12	11.2 $\pm$ .13	10.8 $\pm$ .08
Average		9.6 $\pm$ .11	8.5 $\pm$ .09	9.6 $\pm$ .09	9.2 $\pm$ .06
Reliance					
1933....	90	8.4 $\pm$ .14	6.2 $\pm$ .11	7.7 $\pm$ .14	7.4 $\pm$ .09
1934....	192	11.4 $\pm$ .16	10.0 $\pm$ .13	10.8 $\pm$ .16	10.7 $\pm$ .09
Average		9.9 $\pm$ .11	8.1 $\pm$ .09	9.3 $\pm$ .11	9.1 $\pm$ .06
Marquis					
1933....	90	9.0 $\pm$ .19	6.9 $\pm$ .12	7.6 $\pm$ .14	7.8 $\pm$ .09
1934....	192	9.5 $\pm$ .12	8.9 $\pm$ .13	9.3 $\pm$ .13	9.2 $\pm$ .07
Average		9.3 $\pm$ .11	7.9 $\pm$ .09	8.5 $\pm$ .09	8.5 $\pm$ .06
Hope					
1933....	45	7.3 $\pm$ .17	7.0 $\pm$ .16	7.3 $\pm$ .17	7.2 $\pm$ .10
1934....	192	10.2 $\pm$ .15	10.0 $\pm$ .14	10.7 $\pm$ .16	10.3 $\pm$ .09
Average		8.8 $\pm$ .11	8.5 $\pm$ .08	9.0 $\pm$ .12	8.8 $\pm$ .06

The differences in numbers of hair or fibrous roots per unit section are small and not entirely consistent as between the different soil levels, but nevertheless appear to be greater than can be explained by random errors. On the average for all levels, Ceres has the largest number, Reliance the second largest, and Marquis the least. The difference between Ceres and Reliance may easily be due to random variation and the same may be said of the difference between Marquis and Hope.

In 1933 an estimate was made of the total number of hair roots per plant by determining the number of seminal roots that penetrated three or more feet of soil for each of 20 plants of each of the four varieties. These values, multiplied by the number of hair roots for each seminal root, may be regarded as an index of the total number of hair roots per plant. The indices so determined for each variety are 4,031, 3,891, 3,887, and 3,687 for Ceres, Reliance, Marquis, and Hope, respectively. The number of determinations are too few to permit a definite conclusion as to a relation between number of hair roots on



TABLE 2.—Average diameter and weight of representative roots from three soil levels.

Variety	Num-ber of samples	Soil levels			
		1 to 12 in.	13 to 24 in.	25 to 36 in.	Average 1 to 36 in.
Diameter of Roots, mm					
Ceres ...	20	0.231±0.003	0.209±0.001	0.196±0.001	0.212±0.001
Hope....	20	0.258±0.001	0.251±0.001	0.177±0.001	0.229±0.001
Diff. Hope-Ceres..		0.027±0.003	0.042±0.001	0.019±0.001	0.017±0.001
Weight of Roots, Grams per 192 2-cm Sections					
Ceres ...		0.0651	0.0402	0.0334	0.1387
Reliance		0.0351	0.0310	0.0224	0.0885
Marquis.		0.0551	0.0500	0.0310	0.1361
Hope....		0.0586	0.0327	0.0259	0.1172

the one hand and yield and drouth resistance on the other. However, the differences are such as would be expected if a relation of this kind exists.

On the average the roots of Ceres were smaller in diameter (Table 2) than those of Hope, but here again the differences are not entirely consistent for the different soil levels. Also, contrary to what would be expected, the weight of the roots per unit section was somewhat more for Ceres than for Hope. There seems little reason to expect a relation between yield or drouth resistance, on the one hand, and diameter or weight of roots, on the other, and little if any is indicated in this study.

### SUMMARY AND CONCLUSIONS

The number of fibrous or hair roots per 2-cm section of the roots, and the weight per unit section of the roots of four varieties of spring wheat differing in yield at the Northern Great Plains Field Station, Mandan, N. Dak., and believed to differ in drouth resistance, were determined for different soil levels to a depth of 36 inches in 1933 and 1934. Diameter measurements of the roots of Ceres and Hope were taken at three soil levels. The number of seminal roots per plant penetrating to a depth of 3 feet or more was also determined which, multiplied by the number of hair roots per root, may be regarded as an index of the number of hair roots per plant.

Ceres and Reliance were found to have slightly more hair roots per unit section of root than Marquis and Hope and they likewise appeared to have a larger number of hair roots per plant. The differences were greater than can be explained by random errors, but nevertheless were not entirely consistent at different soil levels.

The data are regarded as indicative only of a relation between yield under conditions of drouth and numbers of hair roots per unit length of root and per plant. Differences in diameter and weight of roots per unit length were observed but little evidence was secured to indicate a relation between these differences and yield or drouth resistance.

## A RESPONSE OF ALFALFA TO BORAX<sup>1</sup>

L. G. WILLIS AND J. R. PILAND<sup>2</sup>

ONE of the greatest difficulties experienced in developing a well-balanced system of agriculture in the southeastern states is associated with a soil peculiarity that has heretofore made it impractical to use lime except at limited rates of application.

For some time liming has been known to promote a deficiency of available manganese on extensive areas, but the soils involved are generally relatively high in residual organic matter because of poor natural drainage.<sup>3</sup> On the lighter sandy soils the characteristic symptoms of manganese deficiency have never been observed even with extremely heavy liming. Recently, a response to boron has been noted on several of the lighter soil types of the state where lime has been used liberally. Heavy applications of lime are also believed to promote a deficiency of potassium, particularly on sandy soils.

Contrary to all of the evidence indicative of adverse effects of heavy liming, one grower has succeeded for 15 years in producing alfalfa on a deep phase of Norfolk sand. Although the soil is extremely low in content of nutrient elements, no unusual fertilizer requirement has been evident. One outstanding peculiarity has been an apparently abnormal requirement for lime. With a weakly buffered soil, having a pH value well above 7.0 from prior liming, it has been necessary in many cases to apply ground limestone at rates up to 5 tons or more to the acre to insure a satisfactory stand with each new planting. While no formal experimental evidence has been obtained to demonstrate this need for lime, it has been observed that fields which have failed, supposedly from too light an application, have produced satisfactory growth where lime has been spilled in unloading from trucks to the distributor.

The grade of lime used was a ground dolomite by-product from a mining industry which contained appreciable amounts of heavy metallic elements such as copper, manganese, and zinc.

### NEGATIVE EFFECT OF MINOR CONSTITUENTS OF LIMESTONE

The possibility that the apparent response to lime was actually due to an effect of these elements was tested experimentally on a field where a recent planting of alfalfa was failing presumably because too small an application of lime had been made. Amounts of copper, manganese, and zinc sulfates equivalent to the content of these elements in 10 tons of the grade of limestone used were applied to

<sup>1</sup>Contribution from the Department of Agronomy, North Carolina Agricultural Experiment Station, State College Station, Raleigh, N. C. Published by consent of the Director of the Agricultural Experiment Station as No. 102 of the Journal Series. Also presented before the Division of Fertilizer Chemistry at the ninety-fourth meeting of the American Chemical Society in Rochester, N. Y., Sept. 7, 1937. Received for publication October 27, 1937.

<sup>2</sup>Soil Chemist and Assistant Soil Chemist, respectively.

<sup>3</sup>WILLIS, L. G. Response of oats and soybeans to manganese on some Coastal Plain soils. N. C. Agr. Exp. Sta. Bul. 257. 1928.

plats in the field. These treatments were placed late in the spring. No effects were noted during the summer and the tests were discontinued.

A few years later the alfalfa began to die on a number of fields regardless of the amount of lime used or the pH of the soil. In appearance, the affected plants resembled those that had previously failed because of an insufficient application of lime. In the latter cases none of the ordinary fertilizer materials had been beneficial.

#### RESPONSE TO BORAX

The possibility of a boron deficiency was introduced by evidence from other experiments of a response to borax, particularly with truck crops on liberally limed soils.<sup>4</sup> Reconnaissance tests with varying amounts of borax placed at random on affected alfalfa fields in early March gave evidence of distinctly beneficial effects from applications of 5 pounds to the acre. The most striking differences were noted during midsummer.

Plants showing the symptoms that were corrected by borax were typically yellow in the terminal growth. Frequently the apical buds were dead and blossoming retarded. Severe wilting occurred during hot dry weather and the plants seemed to be abnormally infested with aphids or leaf hoppers.

#### SUPPLEMENTARY FIELD AND POT EXPERIMENTS

In the results of the preliminary tests there appeared to be sufficient justification for a conclusion that the problem involved only a boron deficiency. There remained, however, the question of the apparent need for excessive quantities of lime and the successful production of alfalfa for years on the land. Following the tests with borax alone, therefore, another more comprehensive experiment was placed on a field where the yellow condition was moderately severe. This consisted of copper, manganese, and zinc sulfates and borax at rates of 5, 10, 10, and 5 pounds, respectively, to the acre, each material being applied to 1/100-acre plats separately and in all possible combinations. In addition, applications of borax were made at rates of 10 and 20 pounds to the acre.

This detail of the experimental work was started in the field late in May and at the same time soil from another field where alfalfa had failed completely was taken to the greenhouse for additional experimentation.

In the field no effects were visible during the year in which the treatments were applied. The soil taken to the greenhouse was put into 1-gallon glazed earthenware pots late in May and alfalfa was seeded. The treatments applied were copper, manganese, and zinc sulfates separately at the rates used in the field and each with borax at a rate of 10 pounds to the acre. No distinct response was noted except from the borax, although there was slight evidence of the occurrence of a parasitic disease on the plants receiving the copper sulfate alone.

The plants grown in the pots developed the typical yellow color in the terminal leaves, sometimes tending toward a red (Fig. 1). The

<sup>4</sup>WILLIS, L. G., and PILAND, J. R. Some observations on the use of minor elements in North Carolina agriculture. *Soil Science*, 44:251-263. 1937.

internodes were short and branches developed at the nodes. Late in September, however, the plants grown without borax improved in appearance and within a few weeks became equal in all respects to those to which borax had been supplied.

This, together with the observation made in the field that the abnormal condition of alfalfa occurred only between late spring and midsummer, suggested the possibility of a relation to photoperiodism. An attempt to verify this possibility experimentally has not been successful, but it suggested an explanation for the failure of borax to produce a beneficial effect when applied late in the season to an old planting.

The field experiment with copper, manganese, zinc, and borax was therefore continued without modification through the second year. In May it was noted that the entire field had developed the yellow color with the exception of some of the treated plots. No attempt was made to harvest these for record as the stand had been reduced unevenly before the treatments had been applied. The plots were classified, however, on the basis of color and relative growth into two groups. In the group designated as A very few or no yellow leaves appeared and the plants were fully twice the height of those in the remainder of the field. Group B contained plants that were predominantly yellow and little or no better than those in the field.

According to this classification the effect of treatment was as follows:

#### Effect of Metallic Elements and Borax on Yellow Alfalfa

##### Group A, normal plants

B  
B Mn  
B Cu Mn  
B Cu Mn Zn  
B Mn Zn  
B Cu Zn

##### Group B, defective plants

Mn  
Cu  
Zn  
B Cu  
B Zn  
Cu Zn

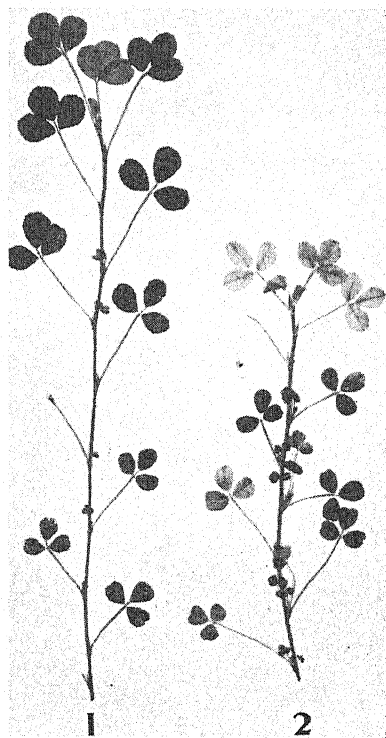


FIG. 1.—Characteristics of alfalfa grown in pots on "yellows" soil. (1) With borax; (2) without borax.

There are three outstanding items to be noted. Borax was distinctly beneficial (Fig. 2) except where it was combined with copper or zinc. Manganese corrected this adverse effect of copper or zinc when used with borax and the combination of copper, manganese, and zinc was as effective as the treatments containing boron. The plots receiving 10 and 20 pounds of borax were approximately equal to those receiving 5 pounds.



FIG. 2.—Left foreground, field response to 5 lbs. of borax to the acre in the second year.

Reverting then to the earlier attempt to demonstrate this effect of the metallic elements, a suggestion is made that the treatments were applied too late in the season to produce a response and that beneficial results might have been noted the following year if the work had been continued. Until further information is available, however, the cause of the abnormal condition of the alfalfa cannot be stated. For practical usage it can be considered a boron deficiency and the simplest and most economical remedy will be borax applied at a rate of 5 to 10 pounds to the acre where the soil is distinctly basic.

#### EXTENT OF THE BORON PROBLEM

At the outset this problem was thought to be confined to the sandy soils. Since the final results have been obtained, however, specimens of alfalfa plants have been received from various parts of the state where the same symptoms of injury have been noted. The soils range from sandy loams to heavy clays. If the causal factors in the latter cases are different from those found in the experiments they cannot be distinguished by plant symptoms. Should there be several distinct

causes of the yellow condition it is probable that the one which is remedied by boron can best be identified by the characteristic increase in severity in early summer and recovery later.

The problem of insect infestation in relation to the boron effect has not been studied systematically. On one field which showed the yellowed condition late in March, aphids were extremely abundant and leafhoppers were either absent or scarce. An alfalfa seeding failed completely in strips through another field where the intended application of manure was missed. Soil from one of these strips was taken to the greenhouse where it was used in a pot experiment. An occasional white fly and aphid was seen on the plants but not in sufficient numbers to have caused any abnormalities. It was in this series of pots that the response to boron already referred to was obtained. Apparently insect infestation is not the primary cause of alfalfa yellows although it may be a contributing factor.

Apparently this condition in alfalfa is extremely common<sup>5</sup> and there is a strong probability that it may be aggravated by the use of fertilizers containing soluble calcium salts since reports indicate that it is very prevalent where superphosphate has been used liberally, and early work<sup>6</sup> has shown that calcium sulfate increases the severity of boron deficiency symptoms.

#### SUMMARY

The yellowed condition of alfalfa which occurred on some soils in midsummer has been corrected by additions of borax. Manganese appears to supplement the effect of borax. Zinc and copper have antagonistic or negative effects, but a combination of manganese, zinc, and copper sulfates produced results similar to those obtained with borax. Borax effectively corrected the abnormal condition when applied in March, but failed when applied late in May of the same year. Tentatively, it is suggested that there is a photoperiodic factor involved.

The yellow condition is general on all alfalfa soils within North Carolina. It seems to be aggravated by liming and by the liberal use of fertilizers high in soluble calcium salts.

Abnormal infestation by sucking orders of insects seems to be associated with the condition of plants which is remedied by borax.

<sup>5</sup>Since this manuscript was prepared, our attention has been called to a report of what is probably an identical condition, described in a paper entitled, "A Yellowing of Alfalfa Due to Boron Deficiency", *Sci. Agr.*, 17:515-517. 1937.

<sup>6</sup>See footnote 4.

## THE TRANSGRESSIVE INHERITANCE OF REACTION TO FLAG SMUT, EARLINESS OF HEADING, PARTIAL STERILITY, AND STIFFNESS OF GLUMES IN A VARIETAL CROSS OF WHEAT<sup>1</sup>

T. H. SHEN, S. E. TAI, AND S. C. CHANG<sup>2</sup>

THIS paper reports a case of transgressive inheritance of several characters in a varietal cross. The study was carried from  $F_1$  to  $F_5$  of a cross between a Chinese variety, Pathology 4592, and an Australian variety, Nebawa. The two parents were practically immune to flag smut, *Urocystis tritici* Koern., at Nanking. They were also medium early, easy in thrashing, and fully fertile. In  $F_2$ ,  $F_3$ ,  $F_4$ , and  $F_5$  of the cross there were some plants susceptible to flag smut, some heading earlier than either parent, some partially sterile, and some having stiff glumes.

### MATERIALS AND METHODS

The parental variety, Pathology 4592, was selected from a farmer's variety at Wei-hsien, Shantung, and Nebawa was obtained directly from Australia. These two varieties were tested by the Pathology Division of the University of Nanking for their reaction to flag smut in 1926-1933, inclusive. They were free from smut infection throughout the nursery tests. A half mou (about  $\frac{1}{2}$  acre) of each was grown in 1933 in addition to the nursery tests. No smut was found in the plot of 4592, although two smutted plants were found in Nebawa. The former, therefore, can be considered as immune and the latter as nearly immune to the biological strains of flag smut found at Nanking. However, both varieties showed a small percentage of flag smut in the tests in Honan and Shensi.

The methods of smut inoculation used previously by the Division of Plant Pathology of the University of Nanking were followed. The fungous spores were supplied every year by the Pathology Division. It was stated that the smut was collected originally from a farmer's field in Nanking in 1925. The spores supplied for this study originated from a single row harvested in 1927 in the hope of having one biological form. For inoculation each envelope containing wheat grains and smut spores was emptied into a brass dipper, 6 cm in diameter, with holes in the bottom. The dipper was then shaken vigorously to insure distribution of the spores on the grain.

In taking notes on smut reaction in this study, the percentage of infection was based on the number of infected plants. In the  $F_3$  progenies, notes were taken on both plant and culm infection for comparison.

The date of heading was taken for each plant as the tip of the first head emerged from the auricle of the top leaf.

The hybrids were first made in the spring of 1932. In order to obtain adequate data on date of heading in  $F_1$  and to increase the size of the population in  $F_2$ , further crosses were made in the spring of 1934 and that of 1936. The  $F_1$  plants were grown together with the parents in the greenhouse prior to 1937, but in 1937

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the  $F_1$  plants were grown with the parents in the plant breeding garden of the University of Nanking to obtain notes on date of heading under field conditions. The  $F_2$ ,  $F_3$ , and  $F_4$  plants were also grown with the parents in the garden. In the field, seeds were sown 3 inches apart in 5-foot rows which were spaced a foot apart. All seeds of the parents and of the  $F_1$ ,  $F_2$ ,  $F_3$ , and  $F_4$  for planting were heavily inoculated with smut spores and then sown in the garden where the study had been carried on during the three previous years. The planting was done about October 20 at which time the temperature was about 60° F. Pathology 1102, a very susceptible variety, was sown around the bed as a guard and as a means of obtaining an available supply of smut spores.

Cytological studies were made on the sterile  $F_5$  plants by using the modified iron acetocarmine smear method described by McClintock.<sup>3</sup>

#### INHERITANCE OF REACTION OF FLAG SMUT

The cross of Pathology 4592 and Nebawa was made to learn whether or not these two varieties have the same genotypes with regard to immunity to flag smut. There were 19 hybrid seeds in 1934 and 109 hybrid seeds in 1936, which were heavily inoculated and sown in the greenhouse and in the garden, respectively. All of the  $F_1$  plants grown either in the greenhouse or field were entirely free from smut. Out of 394  $F_2$  plants grown in the field in 1933-34, 2 plants were partially smutted, i.e., 6 of 12 culms in one plant and 2 of 11 culms in the other being smutted. In another  $F_2$  generation which was grown in 1935-36, 19 out of 1,514 plants were partially smutted. Considered on a percentage basis, the former  $F_2$  gave 0.51% of smut and the latter 1.25%.

In  $F_3$ , 345 progenies from the 394  $F_2$  plants were raised and 80 of them showed a low degree of smut infection. The frequency distribution of the  $F_3$  families with respect to the percentage of flag smut is shown in Table 1. There were two families with the percentage of smut above 10, i.e., one family having 5 smutted out of 54 plants and the other 4 smutted out of 32 plants. The total number of plants grown in  $F_3$  was 24,567 and 143 of them showed smut, giving 0.58% smut.

TABLE 1.—*The frequency distribution of  $F_3$  families with respect to the percentage of flag smut in 1935.*

Classes for smut percentage	0	0.5-2.49	2.5-4.49	4.5-6.49	6.5-8.49	8.5-10.49	10.5-12.49	12.5-14.49	Total
No. of $F_3$ families	265	49	18	7	1	3	1	1	345

Progenies of the two  $F_2$  smutted plants of the 1933-34 crop were grown in  $F_3$ , and one of them did not show any smut, while the other gave 0.97% infection. Neither of these  $F_2$  plants seems to be very susceptible, as one  $F_3$  progeny was free from smut and the other showed only a trace of smut.

<sup>3</sup>McCLINTOCK, B. A method for making acetocarmine smears permanent. Stain Tech., 4:53-56. 1929.



In order to know whether the lines are as susceptible as either Nanking 1102, which has been considered the most susceptible variety, or Nanking 26, which has been considered to be of medium susceptibility, progenies were grown from the 19  $F_2$  susceptible plants of the 1936 crop and the 21  $F_3$  susceptible plants of the 1935 crop, respectively, together with 1102, 26, and the parents. The results are presented in Table 2. Several lines did not show any smut, but some lines did show an even higher percentage of smut than Nanking 1102 and 26. This leads to the conclusion that lines as susceptible as Nanking 1102 and 26 were isolated.

TABLE 2.—*The frequency distribution of  $F_3$  and  $F_4$  families from the susceptible parents with respect to the percentage of flag smut in 1937.*

No. of families	0	0.5-3.9	4.0-7.9	8.0-11.9	12-15.9	16-19.9	20-23.9	24-27.9	28-31.9	Total
$F_3$	12		5			1		1		19
$F_4$	8	3	5	4	1				1	21
Nanking 26				1						
Nanking 1102							1			
Nanking 4592	1									
Nebawa	1									

The percentage of infection in  $F_3$  for those families that showed some smut infection was based on the percentage of culms smutted and the percentage of smutted plants. The plant basis gives a higher percentage of infection than the culm basis. The coefficient of correlation between these two is  $r = 0.676 \pm 0.061$  which is highly significant. The plant basis has been used because it is somewhat easier to determine.

Immunity to flag smut is a dominant character and segregation occurs in  $F_2$ . The factors responsible for immunity in the two varieties Pathology 4592 and Nebawa are not alike. The susceptible plants in  $F_2$  and the susceptible families in  $F_3$  and  $F_4$  were due to the combination of the recessive genes for susceptibility from the two parents. Some lines from the cross between Nebawa and Pathology 4592 were as susceptible as the medium or the most susceptible varieties, such as Nanking 26 and 1102. The genes for flag smut reaction seem to be multiple in nature.

#### INHERITANCE OF EARLINESS

There were 109  $F_1$  plants, 95 plants of Pathology 4592, and 81 plants of Nebawa grown in 1936-37 in the garden. The date of heading of  $F_1$  plants covered practically the whole range of the two parents with a mean close to the early parent. The  $F_2$  population both in 1934 and 1936 was much larger than that of the parents, as shown in Table

3. In both years a number of  $F_2$  plants headed earlier than the early parent, but no plants headed later than the late parent. The  $F_3$  data gave more evidence regarding segregation.

TABLE 3.—Frequency distribution for date of heading of  $F_1$  and  $F_2$  generations and their parents under field conditions.

Generation	Date of heading in class interval*											Total	Mean±S. D.
	1	2	3	4	5	6	7	8	9	10	11		
1934													
P <sub>1</sub> A†			*5	15	2							22	10.773±1.412
P <sub>1</sub> B†				12	21	7	1					41	14.073±2.065
F <sub>2</sub>	12	51	117	93	51	19	2					345	9.583±3.566
1936													
P <sub>1</sub> A		13	28	31	4							76	9.026±2.460
P <sub>1</sub> B						3	24	28	7	1	2	65	22.307±2.919
F <sub>2</sub>	13	112	301	512	356	180	36	3	1			1,514	11.549±3.687
1937													
P <sub>1</sub> A	21	28	12	26	6	1	1					95	7.21±4.13
P <sub>1</sub> B			2	5	9	30	21	10	4			81	18.04±3.86
F <sub>1</sub>	2	2	25	36	28	13	2	1				109	11.80±3.60

\*Size of class interval is 3. Class interval 1 means April 21, 22, and 23 in 1934; April 22, 23, and 24 in 1936; and April 20, 21, and 22 in 1937.

$\dagger P_1A$  = Pathology 4592, and  $P_1B$  = Nebawa.

The mean and S. D. for date of heading were calculated for each  $F_3$  line. The calculated means for the parents, Pathology 4592 and Nebawa, which were grown in the same field with the  $F_3$  in 1935, were 14.195  $\pm$  2.202 and 25.769  $\pm$  2.058, respectively. Three  $F_3$  lines with means of 8.051  $\pm$  2.310, 9.218  $\pm$  2.244, and 11.075  $\pm$  2.781, respectively, headed apparently earlier than the early parent and were also relatively homozygous. Two lines averaged to head on 27.191  $\pm$  3.570 and 28.238  $\pm$  3.105 which is slightly later than the late parent, but their S. D.'s are larger than the late parent. There is some evidence that, although no homozygous lines are significantly later than the late parent, some plants in these two and possibly other lines are genotypically slightly later in heading than the late parent.

The coefficient of correlation between the date of heading and S. D. of the  $F_3$  lines as shown in Table 4 is  $r = -.347$  which leads to Fisher's  $Z = .337$  and its S. E. = .125. The correlation is significantly negative, and although not very large, it indicates that families of late heading with small S. D. are proportionally greater than those of early heading. This relation suggests a partial dominance of early genes over late genes.

The number of genes involved in this cross can not be determined with certainty; but as the mean date of heading of  $F_1$  plants was close to the early parent, the extremely early and late families as well as the parental types appeared in  $F_2$  and  $F_3$ , and relatively homozygous families of  $F_3$  in each class group were indicated with small standard deviation, the genes involved are multiple, the early genes are par-

TABLE 4.—*Classifications of  $F_3$  families on the basis of mean date of heading and standard deviation.*

S. D. (Y)	Mean for date of heading (X)							Total
	7.5- 10.49	10.5- 13.49	13.5- 16.49	16.5- 19.49	19.5- 22.49	22.5- 25.49	25.5- 28.49	
1.4-2.09.....						3		3
2.1-2.79.....	2	1	2	1	1	4	2	13
2.8-3.49.....	4	1	1	2	2	2	1	13
3.5-4.19.....	1	4	5	1	5		1	17
4.2-4.89.....		5	3	2				10
4.9-5.59.....		1	5	2	1			9
5.6-6.29.....		1	1					2
Total.....	7	13	17	8	9	9	4	67

$$r = -.347$$

$$Z = -.337 \pm .125$$

tially dominant over the late genes, and the effect of the genes is rather minute.

It was questioned whether the mean, median, or modal date of heading of  $F_3$  lines was best correlated with the date of heading of the  $F_2$  plants. The coefficient of correlation between them, Fisher's  $Z$ , and the differences between  $Z$  values were calculated and shown in Table 5. All of the coefficients and  $Z$  values were very high, showing that either mean, median, or modal date of heading of  $F_3$  lines can be used with relative reliability. On the basis of differences between  $Z$  values, the correlation between date of heading in  $F_2$  and the median date in  $F_3$  is significantly greater than the correlation between  $F_2$  with either mean, or mode.

TABLE 5.—*Correlating the mean, median, and modal date of heading of the  $F_3$  lines with the date of heading of the  $F_2$  plants.*

Correlation on basis of	r	Z	Z differences
(1) Median.....	0.964	2.000	(1)-(2) = 0.466 $\pm$ 0.177
(2) Mean.....	0.911	1.534	(1)-(3) = 0.633 $\pm$ 0.177
(3) Mode.....	0.866	1.317	(2)-(3) = 0.217 $\pm$ 0.177

### STIFFNESS OF GLUMES

Stiffness of glume was studied by pulling the outer glumes in the middle and top part of the spikelets because those of the base spikelets are usually fairly stiff. The glumes of both parents are not stiff at all. The glumes of  $F_1$  plants were not stiff, but in  $F_2$  there were 312 plants showing normal and 33 plants which were fairly hard to thrash. Their degree of stiffness was not so high as Nilsson-Ehle's speltoid type A, B, or C. Out of the 33  $F_2$  plants that were hard to thrash, the progenies of 16 were tested in  $F_3$ . Three families bred true for stiffness of glumes, the others showed segregation, and one family failed to show stiffness, indicating the possibility of a wrong classification in  $F_2$ . In addition to the 15 families, the progenies of 105  $F_2$  plants that were easily thrashed were tested in  $F_3$ , and 72 progenies segregated from

1% to 55% of plants with stiff glumes. In total, 87 out of 121 progenies tested gave some plants with stiff glumes. The mode of inheritance is rather complicated.

#### PARTIAL STERILITY

Both parents were fully fertile. Both Nebawa and Pathology 4592 produced three seeds per spikelet, the latter occasionally giving four seeds per spikelet with three-seed spikelet as a standard. The  $F_1$  appeared to be completely fertile. Out of 394 plants in  $F_2$ , 3 plants, 288a1-39, 288a1-94, and 288a1-102, were found to be partially sterile. Progenies from two of these plants were tested in  $F_3$ . The family 288a1-39 gave three plants out of a total of eight with 20%, 25%, and 35% of sterility, respectively. The family 288a1-94 gave 6 plants out of a total of 17 with 20%, 25%, 30%, 30%, 70%, and 75% of sterility, respectively. A few other families in  $F_3$  also gave partially sterile plants. Data from these families are given in Table 6. Out of a total of 67  $F_3$  lines grown from  $F_2$  plants that were fertile, 12 lines gave some plants that were partially sterile as shown in Table 6.

TABLE 6.—Frequency distribution of sterile plants in  $F_3$  lines that gave some sterile plants.

Family No.	Total No. of plants	No. of sterile plants	Percentage sterility of $F_3$ lines				
			1-20.9	21-40.9	41-60.9	61-80.9	81-100.9
288a1- 4...	19	1		1			
-39....	8	3	1	2			
-54....	70	2	1	1			
-79....	49	15	2	6	3	4	
-94....	17	6	1	3		2	
a3- 8....	62	1			1		
-27....	69	1	1				
-28....	69	17	1	7	7		2
a4- 7....	59	5	2	2			1
-17....	55	2		1			1
-20....	83	1				1	
-22....	70	3		3			
-31....	79	5	3	2			
-32....	73	4	1	1			2

The progenies of 12  $F_3$  plants with 52.2% to 98.6% sterility were grown in the greenhouse. The three  $F_3$  plants with 92% to 99% sterility produced only one to five poorly developed seeds which failed to germinate. Another  $F_3$  plant with 83% of sterility produced only two  $F_4$  plants with 22% and 50% sterility, respectively. The eight other lines gave 21% to 34% of mean sterility as shown in Table 7.

In order to find out the cytological behavior of those sterile plants, a study was made on the sterile  $F_3$  plants. Microsporocytes of these plants were examined. The results tabulated in Table 8 indicate clearly that the sterile plants arose through some sort of chromosomal aberration. Their somatic chromosome numbers are all below

TABLE 7.—*Sterility in F<sub>4</sub> lines.*

Line number	Percentage sterility of F <sub>3</sub> plants	Total number of plants in F <sub>4</sub>	Mean percentage of sterility $\pm$ S. E. in F <sub>4</sub>
a1-79-43.....	52	30	21.0 $\pm$ 3.7
a1-94-2.....	65	39	27.9 $\pm$ 4.3
a1-94-11.....	70	22	29.5 $\pm$ 3.3
a1-79-47.....	79	14	25.0 $\pm$ 6.6
a1-79-20.....	80	17	20.9 $\pm$ 4.6
a1-79-44.....	84	59	33.6 $\pm$ 3.6
a1-79-46.....	84	4	18.0 $\pm$ 1.6
a1-94-5.....	85	17	33.2 $\pm$ 4.9

the normal hexaploid (42) and range from 30 to 35. The observed chromosome conjugations are rather variable, ranging from univalents to tetravalents. The lowest number of bivalents is 13 and the highest 16, and both 14 and 16 were most frequently observed. The number of univalents ranges from 0 to 5 and from 0 to 4 at the first and the second metaphase stages, respectively, and the number of lagging chromosomes was found to be from 0-4 and from 0-6 during the first and the second anaphase stages, respectively. Spore quartets with extra small nuclei were frequently observed, ranging from 5.5% to 32.6% of the cells studied. Aborted pollen grains were also found, the lowest percentage being 1.3 and the highest 38.5. These variations seem to have their origin in the variation of somatic chromosome numbers, hence in the variation of chromosome conjugations.

Plants with 21 pairs of chromosomes were frequently observed. They were fully fertile and normal, just as their parents. Evidently the sterile plants have been constantly throwing out normal hexaploid plants. But those F<sub>3</sub> plants with 30 to 35 somatic chromosomes (showing less than 7 univalents in their chromosome conjugation) will be unable to give rise to progenies with 42 somatic chromosomes, because so far as the observed chromosome conjugations are concerned, there is no way for them to form gametes with 21 chromosomes, even figured on the basis that all bivalents behave normally and all univalents go to the same pole during anaphase. It may be predicted upon this basis that there would be no plants in the next generation possessing 42 somatic chromosomes.

As to the exact origin of the chromosomal aberration, it is not certain. Similar partial sterility has been frequently observed by L. Y. Shen and the writers in Chinese-foreign wheat varietal crosses. Furthermore, wheat has been grown in China for over 4,000 years, which is far longer than foreign wheats, especially those of American, Australian, and European origin, hence the chromosomes of the Chinese wheats may be more differentiated than those of the foreign wheats. More intensive study will be made in those Chinese-foreign wheat varietal crosses in which partial sterility has been observed in order to ascertain the cause of the chromosomal aberration. If the F<sub>1</sub> plants and the first sterile F<sub>2</sub> plants were studied cytologically, the cause of the chromosomal aberration in this cross might be understood more fully. At any rate, the occurrence of those sterile plants

TABLE 8.—*Showing the cytological results in the partially sterile F<sub>2</sub> lines of the cross Pathology 4592 × Nebawa, 1937.*

F <sub>2</sub> families	No. of univalents		No. of lagging chromosomes		Spore quartets with extra small nuclei, %	Aborted pollen grains, %	Chromosome conjugation†
	IM*	IIM*	IA*	IIA*			
ai-79-20-7	0-1	—	1	—	0	—	16 <sub>II</sub> +1 <sub>I</sub> ; 21 <sub>II</sub> .
ai-79-20-10	0	—	0	—	0	0	21 <sub>II</sub> .
ai-79-43-10	0-1	—	—	—	0	1.3	21 <sub>II</sub> .
ai-79-43-25	0-3	—	0-3	0-1	22.0	12.8	16 <sub>II</sub> +1 <sub>I</sub> ; 16 <sub>II</sub> +3 <sub>I</sub> ; 21 <sub>II</sub> .
ai-79-44-8	0	0	0	0	0	0	21 <sub>II</sub> .
ai-79-44-29	0-4	—	0-4	—	11.1	11.2	14 <sub>II</sub> +4 <sub>I</sub> .
ai-79-44-47	0-5	—	—	0-2	0	10.2	13 <sub>II</sub> +4 <sub>I</sub> ; 14 <sub>II</sub> +5 <sub>I</sub> .
ai-79-44-53	0-2	—	—	0-2	18.7	—	16 <sub>II</sub> +2 <sub>I</sub> ; 21 <sub>II</sub> .
ai-79-44-59	1	—	—	—	6.7	—	—
ai-79-46-2	0-5	—	—	—	—	—	—
ai-79-47-4	0-1	—	0-1	—	—	0	21 <sub>II</sub> .
ai-94-2-1	1	—	—	—	—	—	—
ai-94-2-3	0-3	—	—	0-2	16.7	—	1 <sub>III</sub> +13 <sub>II</sub> +3 <sub>I</sub> ; 21 <sub>II</sub>
ai-94-2-4	0-3	0-4	0-4	0-6	32.3	38.5	1 <sub>IV</sub> +14 <sub>II</sub> ; 16 <sub>II</sub> +1 <sub>I</sub>
ai-94-2-11	0-3	—	—	—	17.6	31.9	—
ai-94-2-15	0	0	—	—	0	0	21 <sub>II</sub> .
ai-94-2-23	0-3	—	0-2	0-1	32.2	7.1	—
ai-94-2-37	0	—	—	—	0	—	21 <sub>II</sub> .
ai-94-5-11	0-2	—	0-2	0-1	20.7	11.3	1 <sub>III</sub> +14 <sub>II</sub> +2 <sub>I</sub> ; 1 <sub>IV</sub> +14 <sub>II</sub> +1 <sub>I</sub> ; 21 <sub>II</sub> .
ai-94-11-3	0-2	—	0-1	0-2	5.5	—	—
ai-94-11-13	0	0	0	0	0	0	21 <sub>II</sub> .
Pathology 4592	0	—	0	0	0	0	21 <sub>II</sub> .
Nebawa	0	—	0	—	0	0	21 <sub>II</sub> .

\*IM and IIM stand for first and second metaphase stages, respectively. IA and IIA stand for first and second anaphase stages, respectively.

†I stands for univalent, II for bivalent, III for trivalent, etc. Four or five F<sub>2</sub> plants were studied in each line and about five successful smears were used for each plant. The result represents a summary study of plants in each line.

from  $F_2$  through  $F_5$  generations is due to chromosomal aberration, just as suggested before the cytological study was made.

#### INHERITANCE OF AWNS, SHAPE OF BEAK, AND COLOR OF KERNEL

Pathology 4592 is bearded, while Nebawa has a few apical short awns. The  $F_1$  was semi-bearded. There were 259 plants in  $F_2$  that were either beardless or semi-bearded and 83 bearded plants, fitting a 3:1 ratio with partial dominance of beardless as usual. The bearded plants bred true in  $F_3$ , but the progeny of semi-bearded showed segregation. The apically awned plants bred true.

The shape of beak was also studied. Pathology 4592 is bearded with pointed beak and Nebawa is beardless with blunt beak.  $F_1$  is semi-bearded with blunt beak. The inheritance of these two characters in  $F_2$  is shown in Table 9. There were 250 plants with blunt beaks and 94 plants with pointed beaks, fitting a 3:1 ratio.

TABLE 9.—*Inheritance of awnedness and shape of beak in  $F_2$ .*

Family No.	Beardless, blunt beak	Beardless, pointed beak	Bearded, blunt beak	Bearded, pointed beak
288a1	74	4	0	27
a2	54	4	0	16
a3	27	3	0	7
a4	29	0	0	6
a5	67	1	0	26
Total.....	250	12	0	82

The  $F_3$  data proved pointed beak breeding true, while some of the blunt beak  $F_2$  plants segregated for blunt and pointed beaks in  $F_3$ . The very close association between pointed beak and presence of awn and blunt beak and absence of awn took place in  $F_3$ .

Out of 12 beardless and pointed beak plants, 6 plants were tested further in  $F_3$ . The result is given in Table 10. They segregated into bearded and beardless. The beaks of the beardless plants were not as pointed as those of the bearded ones and not as blunt as those of the beardless plants in the other families. Some of the beardless plants should be heterozygous and should have intermediate pointed beaks. The remainder of the beardless plants should be homozygous and blunt in beak if these characters are assumed as due to the same genes.

TABLE 10.—*The genetic behavior of  $F_3$  progeny of some beardless pointed beak  $F_2$  plants.*

Family No.	Beardless, pointed beak	Bearded, pointed beak
288a1-11	38	21
-46	16	9
-73	28	12
a3-12	43	11
-22	38	13
-36	45	15

The color of kernel is another difference between the two parents. Nebawa has white kernels and Pathology 4592 has red ones. The  $F_1$  kernel color was intermediate red, while in  $F_2$  there were 339 red-kernelled plants and 6 white. The  $F_2$  plants with white kernels bred true in  $F_3$  and some of the red ones bred true while others gave segregation. Thus it is concluded that the color of kernel in this case is due to three pairs of genes.

#### RELATIONSHIP OF THE CHARACTERS STUDIED

It is of interest to see whether there is a linkage relationship between the characters studied. As there were only two plants in  $F_2$  showing smut, the relationship between the reaction to smut and the date of heading was studied in  $F_3$ . The frequency distribution of the median dates of heading in the smut-free and the smutted families are compared in Table 11,  $X^2 = .0484$  and  $P$  greater than .99, showing no significant difference between these two distributions.

TABLE 11.—Probability showing whether the smut damaged and smut-free distributions with regard to the date of heading in  $F_3$  are random samples of the same population.

Median date of heading of $F_3$ families	5-10.99	11-16.99	17-22.99	23-28.99	Total	Chances
Smutted (1).....	7	15	8	3	33	.2308
Free (2).....	22	51	26	11	110	.7692

As there are only a few smutted plants in the so-called "smutted families" in  $F_3$ , the comparison between the average dates of heading of the smutted and the smut free plants in the same family is not entirely reliable. There seems to be no consistent difference between date of heading of the smutted and smut-free plants in the same  $F_3$  lines as shown in Table 12.

The relation between the reaction of plants to flag smut and stiffness of glume was also studied by  $X^2$  for independence, as shown in Table 13. The  $P$  value between 0.30 and 0.50 indicates no association of these two characters. There were 64 beardless and 16 bearded plants and 78 red and 2 white kernels in the five smutted families of  $F_3$ . They showed normal ratios without over production of certain types.

The mean of the median date of heading of those families showing some stiff-glumed plants is  $15.789 \pm 0.560$  and that of non-stiff-glumed plants is  $14.955 \pm 0.760$ . Their difference is  $0.843 \pm 0.944$ , which is not significant. The average date of heading of the stiff-glumed plants did not show a consistent difference from that of the non-stiff-glumed plants in the same family.

It is of interest to study the relationship between stiffness of glume and sterility in  $F_3$  lines because there is the possibility that both characters may be due to chromosomal aberration.  $X^2$  for independence was studied and the probability of 0.224 was obtained, as shown





The independent inheritance of the reaction to smut, stiffness of glume, date of heading, presence and absence of awn, and color of kernel indicates that the genes for these characters are carried in different chromosomes or at a considerable distance apart in the same chromosomes. It seems probable that different chromosomes contribute the genes for the transgressive inheritance of the reaction to flag smut, date of heading, and stiffness of glume in this cross.

### SUMMARY AND CONCLUSIONS

A cross was made between a Chinese variety and Nebawa introduced from Australia. Both varieties are common wheat, *Triticum vulgare*. A genetical study was made in the  $F_1$ ,  $F_2$ ,  $F_3$ , and  $F_4$  of this cross. The two parents were free from flag smut and were medium late, easy in thrashing, and fully fertile. The  $F_2$ ,  $F_3$ , and  $F_4$  of the cross gave a small percentage of susceptible plants. The genes for flag smut reaction appear to be multiple in nature.

A part of the population in  $F_2$  headed earlier but none later than either parent. In  $F_3$  several progenies headed significantly earlier than the early parent 4592 and a few plants in  $F_3$  headed slightly later than the late parent, Nebawa. The genes responsible for earliness of heading seem to be multiple in nature, and the early genes are partially dominant over the late genes.

Some plants in  $F_2$  and  $F_3$  had stiff glumes and some were partially sterile. Transgressive inheritance of the first three pairs of characters was obtained. This is a good example of a geographically distant cross giving transgressive inheritance. The authors have obtained a similar case of transgressive inheritance in earliness from a cross between Prelude, an American variety, and Nanking 2905, a Chinese improved strain by head selection from a native variety. L. Y. Shen obtained transgressive inheritance of earliness in her crosses between Chinese and foreign varieties. Accumulation of such cases may reveal the origin of hereditary variations. Crosses of polyploid varieties may give better chances for obtaining transgressive inheritance than crosses between diploids. The segregation of partial sterile plants resulted from chromosomal aberration.

## NOTE

EXTENSION OF ALFALFA ROOTS INTO SUBSOIL  
DRIED BY A PREVIOUS CROP

SEVERAL investigators have studied the question as to whether or not plants can extend their roots into dry soil. The conclusion has usually been that they can not do so.

In various studies reported from the Kansas Agricultural Experiment Station it has been shown that on the soil of the station farm, which is moderately heavy in the deep subsoil, alfalfa removes the water very thoroughly to depths of approximately 20 feet. It becomes of interest and practical importance to determine whether the roots of a new crop of alfalfa sown on old alfalfa land can penetrate subsoil dried by the previous crop. An experiment in which alfalfa was seeded on old alfalfa land from which subsoil moisture had been removed to about the wilting coefficient (as determined from the moisture equivalent) to depths of approximately 20 feet offered an opportunity to study this question. Plats in this experiment were fallowed for periods of time varying from one summer to 5 years before reseeding to alfalfa. At the end of the experiment the roots were investigated in a plat which had been fallowed one summer and also those in a plat fallowed 3 years. The new alfalfa stands on these plats were then 4 years old and 2 years old, respectively. Excavations were made, the hole in each plat being 12 feet square. The roots were carefully worked out from one side of the hole by means of ice picks.

The data obtained from moisture samples taken at intervals throughout the experiment to a depth of 25 feet showed that the plat fallowed only one summer had accumulated water to a depth of 8 feet, or less, before the new crop was seeded. The plat fallowed 3 years had regained moisture to well above the wilting coefficient throughout the depth to which the previous crop had dried the soil. The last soil moisture samples were taken under the alfalfa sod 6 months before the roots were excavated. Experiments have repeatedly shown here, however, that there is no measurable accumulation of moisture under established alfalfa stands below a depth of about 3 feet.

In the plat fallowed one summer roots could not be traced below depths of 10 to 12 feet except where a few had entered old channels left by the decay of the roots of the previous crop and extended to a maximum depth of 17 feet. In the plat fallowed for 3 years numerous roots of the new crop could be traced to depths of 19 to 20 feet.

Since roots could not be traced beyond 20 feet, it appears that the moisture which has always been encountered at, or slightly below, this level in subsoil moisture studies under alfalfa on this soil is beyond the maximum penetration of the alfalfa roots. This conclusion is further supported by the fact that holes bored with an auger in the bottoms of these pits to a depth of 29 feet showed no permanent water table.—W. H. METZGER, *Kansas Agricultural Experiment Station*, and C. O. GRANDFIELD, *Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.*

## BOOK REVIEW

### A TEXTBOOK OF PLANT VIRUS DISEASES

*By Smith, Kenneth M. Philadelphia: P. Blakiston's Son & Co., Inc.  
× 615 pages, illus. 1937. \$5.*

THREE years ago Smith wrote a book, "Recent Advances in Plant Viruses", apologizing somewhat for presenting a book when knowledge of the subject was in such a flux. He said the earlier book was no textbook, but all the usual textbook subject matter was there—nature of viruses, symptomatology, transmission, physiology, etc.

The book under review is called a textbook, but in reality it is a reference book classifying all of the plant viruses known and giving a little discussion of each, their properties, mode of transmission, etc., and the diseases they cause. The viruses are classified on the basis of the chief host plant involved. This is essentially the classification proposed by James Johnson several years ago, but improved by using the Latin name of the plant instead of the English common name which may lead to confusion. When more than one virus attacks the key host plant, the viruses are numbered consecutively. The author discusses 18 such viruses on *Solanum* and 15 on *Nicotiana*.

A very useful appendix is included where the host plants are listed alphabetically by the Latin name; the virus symptoms and their causes are listed for each. A special chapter is devoted to the insects, etc., concerned in the transmission of plant viruses, and the last chapter discusses suspected virus diseases requiring further study.

It is the opinion of the reviewer as a non-virus plant pathologist, that this is the most satisfactory and useful book on viruses yet to appear because it makes the problem of identification so simple. (J. G. H.)

## FELLOWS ELECT FOR 1937

## OLAF SVERRE AAMODT



OLAF SVERRE AAMODT, University of Wisconsin, Madison, Wisconsin. Born at St. Paul, Minnesota, August 9, 1892. B. S. University of Minnesota, 1917; M. S. 1922; Ph.D., 1927. Scientific Assistant in Plant Pathology, Office of Cereal Investigations, U. S. Dept. of Agriculture and University of Minnesota, 1917, 1920-23. Instructor in Crop Improvement, American Expeditionary Forces in France, 1918-19. Assistant Pathologist, Office of Cereal Investigations, U. S. Dept. of Agriculture and University of Minnesota, 1921; Associate Pathologist 1923. Instructor in Genetics, University of Minnesota, 1924-26. Associate Professor of Genetics and Plant Breeding, University of Alberta, Edmonton, Alberta, 1928; Professor, 1931; Head of De-

partment of Field Crops, 1932-35. Professor of Agronomy and Chairman Agronomy Department, University of Wisconsin, Madison, Wisconsin, 1935-.

Member American Society of Agronomy, A.A.A.S. (Fellow), American Phytopathological Society, Genetics Society of America, Western Canadian Society of Agronomy, and Canadian Society of Technical Agriculturists.

Dr. Aamodt's first important contributions were in the field of flax and cereal breeding, with special emphasis on disease resistance. These consist of numerous studies reported in scientific journals, and cooperation in the production of several successful and widely used varieties such as Redwing flax, Thatcher, and Ceres wheats and Newal barley. At present his major interests are in the agronomic phases of the conservation movement, pasture improvement, and the breeding of grasses and legumes.

He has been a member of the Society for many years and served as Chairman of the program committee for the Crops Section for 1937.

## WILLIAM ALBERT ALBRECHT

WILLIAM ALBERT ALBRECHT, born at Flanagan, Livingston County, Illinois, September 12, 1888. Reared on a good Illinois farm. Attended the University of Illinois, receiving an A.B. degree in 1911. Taught at Bluffton College, Bluffton, Ohio, 1911-1912. Re-entered the University of Illinois and secured the degree of B. S. in Agriculture in 1914, M.S. in Agronomy in 1915, Doctor of Philosophy in 1919. During part of this time he was assistant in botany in the University of Illinois, coming to the University of Missouri in September 1916 as instructor in soils, where he later became assistant professor, associate professor, and finally full professor.

Dr. Albrecht is a member of Alpha Zeta, Gamma Sigma Delta, Sigma Xi, Phi Kappa Phi, and an honorary member of the Farm House and Alpha Gamma Sigma fraternities. He has served in various



active in connection with the organization of the Soil Science Society of America, of which he will be Chairman in 1939.

Dr. Albrecht has given particular attention to soil biology and has between 25 and 30 publications to his credit, primarily in this field. A considerable number of graduate students have taken doctorates under his direction. Dr. Albrecht is very much interested in practical as well as scientific agriculture, owning a considerable acreage of good Illinois land. He is a very popular instructor at the University of Missouri and is a respected counselor for a large number of students.

#### FIRMAN EDWARD BEAR

**F**IRMAN EDWARD BEAR, Crowell Publishing Company, New York City. Born near Germantown, Ohio, May 21, 1884. B.S.A., Ohio State University, 1908; M.S., 1910; Ph.D., University of Wisconsin, 1917. Instructor Agricultural Chemistry, Ohio State University, 1908-1910; Assistant Professor, 1910-1913; Professor of Soils and in Charge Soil Investigations, West Virginia University, 1914-1916; Professor of Soils, Ohio State University, 1916-1929; Director Agricultural Research, American Cyanamid Company, 1929-1937; Science Editor, *The Country Home Magazine*, 1937-.

Member (Fellow) of A. A. A. S., American Society of Agronomy; Soil Science Society of America; American Chemical Society, and Sigma Xi. Special interests: Liming, nitrogen fixation, use of fertilizers, and pasture management.

Dr. Bear has served on special committees of the Society and has been a frequent contributor to the annual programs of the Society. He has been a leader in pasture management and the subject of fertilizer use, and is the author of two well-known books, "Soil Management" and "Theory and Practice in the Use of Fertilizers".



#### HARRY OLIVER BUCKMAN



**H**ARRY OLIVER BUCKMAN, Cornell University, Ithaca, New York. Born on a farm near West Liberty, Iowa, July 4, 1883. B.S.A., Iowa State College, 1906; M.S., 1907; Ph.D., Cornell University, 1912; Assistant in Chemical Section, Iowa Experiment Station, 1906-7; Assistant Agronomist, Montana Experiment Station, 1907-9; Assistant Professor of Soil Technology, Cornell University, 1912-17; Professor of Soil Technology since 1917.

Member American Society of Agronomy, Soil Science Society of America, International Society of Soil Science, and the A. A. A. S. His main interest is in the field of teaching but for many years much of his attention was directed to the formation and classification of soils. He has served on various committees of the Society dealing with soil teaching and has presented a number of papers at the

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Member American Society of Agronomy, Soil Science Society of America, International Society of Soil Science, and the A.A.A.S. His main interest is in the field of teaching but for many years much of his attention was directed to the formation and classification of soils. He has served on various committees of the Society dealing with soil teaching and has presented a number of papers at the



Doctor Buckman is best known to soil scientists as co-author with Dr. T. L. Lyon of the text book, "The Nature and Properties of Soils", which has gone through several editions and which has been an outstanding contribution in its field since it first appeared in 1921.

#### GUY WOOLARD CONREY



GUY WOOLARD CONREY, Ohio Agricultural Experiment Station, Wooster, Ohio, and Ohio State University, Columbus, Ohio. Born Northboro, Iowa, December 10, 1887. University of Michigan A. B. in 1908, M. A. in 1909; Ohio State University Ph.D. in 1921. Assistant in Physical Chemistry, University of Michigan, 1908-1909; Assistant in Division of Soils, Wisconsin Geological and Natural History Survey, 1909-1917; Instructor in Soils, University of Wisconsin, 1914-1917; Instructor in Soils, Ohio State University, 1917-1921, Assistant Professor of Soils 1921-1926, Associate Professor of Agronomy 1930-1937, Professor of Agronomy 1937-; Assistant in Soils, Ohio Agricultural Experiment Station, 1917-1925, Associate Agronomist in

Charge Soil Survey 1925-.

Member of American Society of Agronomy, Soil Science Society of America, International Society of Soil Science, American Association for the Advancement of Science, and Ohio Academy of Science. Member of Sigma Xi, Phi Lambda Upsilon, and Gamma Sigma Delta honorary societies.

Until merged with the S.S.S.A. in 1936, Dr. Conrey participated actively in the work of the American Soil Survey Association, was chairman of several important committees, and President of the Association in 1925.

Although conversant with soil science and agronomy in their broader aspects, Dr. Conrey's chief interest has centered in soil development and classification, agricultural evaluation of soils, land appraisal, and land use.

He has published numerous papers on soil genesis and morphology, and is joint author of 21 county soil survey reports, 6 in Wisconsin and 15 in Ohio.

#### HAROLD DeMOTT HUGHES

HAROLD DeMOTT HUGHES, Iowa State College, Ames, Iowa. Born at Antioch, Illinois, January 16, 1882. B.S., University of Illinois, 1907; M.S.A., University of Missouri, 1908; Instructor in Farm Crops, University of Missouri, 1907-1910; Professor of Farm Crops, Iowa State College and Iowa Agricultural Experiment Station, 1910-.

Member A.A.A.S., American Society of Agronomy, and Association of Official Seed Analysts (President in 1917). His special interests are legumes and grasses for hay, pasture, and green manure; pasture improvement and management. Senior author of "Crop Production". Member of Weather Bureau Committee of the President's



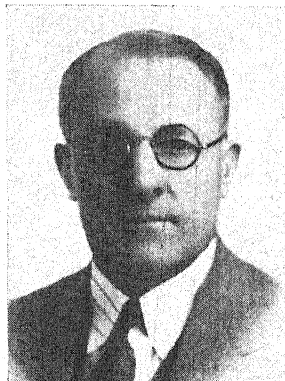
Professor Hughes has been a member of the Society for many years and has served on committees on Pasture Research and Hybrid Corn.

### FRANKLIN DAVID KEIM

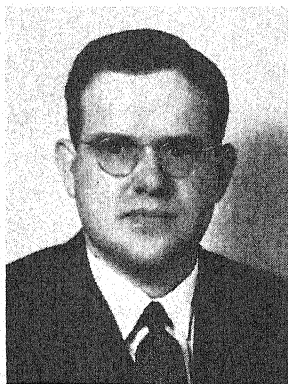
**F**RANKLIN DAVID KEIM, University of Nebraska, Lincoln, Nebraska. Born at Hardy, Nebraska, September 10, 1886. B.S., University of Nebraska, 1914; M.S., University of Nebraska, 1918; Ph.D., Cornell University, 1927. Assistant Agronomist, University of Nebraska, 1914-1916; Extension Agronomist, 1917-1918; Professor of Agronomy, 1918; Acting Chairman, Department of Agronomy, 1930-1932; Chairman, Department of Agronomy, 1932 to date.

Member of A.A.A.S., American Society of Agronomy, the American Genetic Association, and Ecological Society of America. His special interests include plant breeding and genetics, research in weed control, and ecological studies of native grasses with reference to pasture and meadow utilization.

Doctor Keim has been a member of the Society for many years and has served it on several committee assignments.



### ROBERT DONALD LEWIS



**R**OBERT DONALD LEWIS, Ohio State University and Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, Columbus, Ohio. Born Wyalusing, Pennsylvania, November 4, 1897. B.S., Pennsylvania State College, 1919; Ph.D., Cornell University, 1926. Student Assistant in Agronomy, Pennsylvania State College 1917-1919; Instructor in Agronomy, 1919-1922; University Fellow in Agriculture, Cornell University 1922-1923; Assistant in Plant Breeding, 1923-1924; Instructor in Plant Breeding, 1924-1926; Assistant Professor of Plant Breeding Extension, 1926-1930; Professor of Agronomy Extension, Ohio State University, 1930-; Associate Professor of Agronomy (resident teaching), 1933-; Agent,

Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. D. A., 1936-.

Member of the American Society of Agronomy, the Genetics Society of America, and fellow in the American Association for the Advancement of Science. Also a member of Sigma Xi, Alpha Zeta, Gamma Sigma Delta, and Phi Kappa Phi.

Since 1924 Dr. Lewis has been closely associated with state and national seed improvement programs. He has been Secretary-Treasurer of the Ohio Seed Improvement Association since 1930; an active member of various committees of

I. A. Committee on Certified Seed Shows at the International Grain and Hay Show; chairman 1934 to date, I. C. I. A. Committee on Red Clover, Alfalfa, and Grass Seed Certification. Dr. Lewis was secretary, Extension Agronomists, Annual Meeting of 1933; chairman, Crops Section of the A. S. A. in 1935, A. S. A. representative on Seed Council of North America in 1937; and chairman 1937-1938 of Executive Committee of the Corn Improvement Conference.

Dr. Lewis has done outstanding work in developing action programs based upon the correlation and integration of research and extension activities in agronomy. He has also assisted in developing Ohio's approach to the problem of better land use. He has made many valuable contributions to agronomic literature, including both extension and research publications.

### JAMES DOUGLASS LUCKETT



JAMES DOUGLASS LUCKETT, New York State Agricultural Experiment Station, Geneva, N. Y. Born in Washington, D. C., December 5, 1891. B. S. A., Purdue University, 1916; M. S. A., 1919. Scientific Assistant, Bureau of Entomology, U. S. Dept. of Agriculture, Vienna, Virginia, 1913-14; Assistant Chemist, Indiana State Chemist's Laboratory, Lafayette, Indiana, 1916; Editor, Field Crops Section, *Experiment Station Record*, U. S. Dept. of Agriculture, Washington, D. C., 1916-20; Editor, New York State Agricultural Experiment Station since 1920.

Member of the American Society of Agronomy, the American Association of Agricultural College Editors, Sigma Xi, and Fellow of the A. A. A. S.

Mr. Lockett served as Assistant Editor and Business Manager of the JOURNAL of the American Society of Agronomy under Dr. R. W. Thatcher from 1924 to 1928, and has served as Editor of the JOURNAL since 1928.

### HARVEY L. WESTOVER

HARVEY L. WESTOVER, Senior Agronomist in charge of Alfalfa Investigations in the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, is a native of New York State where he spent his earlier years on a farm, graduating with the degree of B.S.A. from Cornell University in 1906. His first official appointment was as Scientific Assistant in the Bureau of Soils in 1906, in which capacity he took part in numerous soil surveys in various parts of the United States. On January 1, 1914, he transferred to what is now the Division of Forage Crops and Diseases, where in addition to alfalfa investigations, his main project, he has conducted experiments with root crops for livestock, silages, and turf grasses. He is a recognized authority on alfalfa in the United States and has published



Westover has taken part in several plant exploration expeditions. In 1924 he was sent to Argentina and Chile in search of new alfalfas; in 1929 to Russian Turkistan and continental Europe, and in 1930 to Spain and North Africa in search of alfalfas resistant to bacterial wilt; in 1934 to Turkistan and Turkey in search of plants for erosion control; and in 1936 to Turkey in search of new forage crops, vegetables, and ornamentals. More than 6,000 introductions resulted from these expeditions. Many lots of alfalfa seed obtained from Turkistan have proved highly resistant to bacterial wilt and are being used in the breeding program. In the preliminary trials other legumes and grasses appear promising for various purposes in the United States.

In 1934, Westover was Chairman of the Crops Section of the American Society of Agronomy, in which capacity he served until about May 1, when his official duties took him to Russia. He is Permanent Secretary of the Alfalfa Improvement Conference, and in 1937 was a member of the committee on alfalfa, clovers, and grasses of the International Crop Improvement Association. From 1927 to 1932 he was a member of the research committee and the executive committee of the United States Golf Association Green Section, serving as Acting Chairman of the former from 1927 to 1929.

He is a fellow of the American Association for the Advancement of Science, a member of the American Museum of Natural History, American Forestry Association, National Geographic Society, the Botanical Society of Washington, the Cosmos Club, and the Explorers Club.

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SOIL MICROBIOLOGY OF INTERNATIONAL SOCIETY OF  
SOIL SCIENCE

THE preliminary meetings of the Third Commission on Soil Microbiology of the International Society of Soil Science, will be held in New Brunswick, New Jersey, on Wednesday, August 30, 1939. The meetings will last until Saturday or the date of the beginning of the Third International Microbiological Congress which is to be held in New York City on September 2, 1939. The meetings of the Commission on Soil Microbiology are arranged in cooperation with Section VIII on Agricultural and Industrial Microbiology of the Microbiological Congress.

The following subjects will be considered at the meeting of the Third Commission: (1) Legume bacteria; (2) microbiology of organic matter decomposition; and (3) the soil population. Titles of papers to be presented before this Commission should be submitted not later than July 1, 1938. The complete papers should be sent in before January 1, 1939. It is hoped that these papers will be published in a volume of Proceedings, before the meetings.

All correspondence concerning these meetings should be addressed either to Dr. H. G. Thornton, Rothamsted Experimental Station, Harpenden, England, or Dr. S. A. Waksman, New Jersey Agricultural Experiment Station, New Brunswick, N. J.

### MEETING OF AGRONOMISTS INTERESTED IN BARLEY GENETICS

ON the afternoon of December 1, 1937, at the Stevens Hotel in Chicago was held a meeting of agronomists interested in barley genetics. At that time an informal organization of workers in the field of barley genetics was formed with D. W. Robertson appointed as Secretary.

A summary of the present linkage work on barley will be prepared and furnished the various workers in the field. An additional committee was appointed, comprising G. A. Wiebe and D. W. Robertson, to revise the nomenclature and allot new symbols as new characters are found and their inheritance determined.

It is hoped that the organization will act as a clearing house for workers in barley genetics. Where possible, linkage groups and characters will be allotted among the workers in an attempt to prevent duplication and in order to verify the results obtained.

### NEWS ITEMS

W. T. G. WIENER, Secretary-Treasurer of the Canadian Seed Growers' Association of Ottawa, Canada, was elected President, for a two-year term, of the International Crop Improvement Association at a meeting of the Association held in Chicago, Ill., November 30, 1937.

DR. A. J. PIETERS, formerly Principal Agronomist, Division of Forage Crops and Diseases, U. S. Dept. of Agriculture, has been granted a year's extension in the service by the President and transferred to the Soil Conservation Service where he will be engaged during the coming year in a study of *Lespedeza*.

DR. R. H. WALKER, Conservationist at the Intermountain Forest and Range Experiment Station was recently elected Director of the Agricultural Experiment Station at the Utah State Agricultural College, Logan, Utah, where he will assume his new duties after March 1. Dr. Walker was formerly a member of the staff as Assistant Professor of Agronomy at the Colorado State Agricultural College, and from 1928 to 1936 was Research Associate Professor of Soils at Iowa State College, where he was in charge of the soil bacteriological investigations. At the Intermountain station he has had charge of the artificial reseeding investigations in the division of range research.



# JOURNAL OF THE American Society of Agronomy

VOL. 30

FEBRUARY, 1938

No. 2

## OXIDATION-REDUCTION POTENTIALS IN ORCHARD SOILS<sup>1</sup>

R. E. STEPHENSON, C. E. SCHUSTER, AND JOE SPULNIK<sup>2</sup>

ORCHARD soils studied at the Oregon Agricultural Experiment Station (7)<sup>3</sup> have shown great variation in physical properties, texture, structure, and aeration. Root distribution and variations in tree growth were found to be correlated with soil conditions. The deep soil horizons of some heavy soils appeared to be anaerobic during a greater part of the season. This condition raised the question as to whether such soils would show low oxidation-reduction potentials, which correlate with their lack of suitability for root development and tree growth.

### HISTORICAL

A good review of the literature concerning the relation of oxidation-reduction potentials to the properties and conditions of soils has been made by Bradfield and associates (1) and by Sturgis (8). Willis (9), Peech and Batjer (6), Bradfield and others (1), and Brown (2) have given improved methods for the study of oxidation-reduction potentials of soils.

Darnell and Eisenmenger (3) have reported that rapid decomposition of organic matter in the soil brought about a marked fall of potential, and they attributed this to oxygen depletion. They conclude that change in acidity, resulting from biological processes associated with the breaking down of fresh organic matter, and a reduction in the oxygen supply are the chief causes of reduced potentials in soils.

Heintze (4) questions the diagnostic value of oxidation-reduction measurements on soils.

### METHODS OF STUDY

Soil samples were collected by 1-foot horizons, except the surface foot which was in two 6-inch sections. Samples of the soil were suspended in N/10 H<sub>2</sub>SO<sub>4</sub>.

<sup>1</sup>Published as Technical paper No. 276 with the approval of the Director of the Oregon Agricultural Experiment Station, Corvallis, Ore. Contribution from the Soils Department in cooperation with the U. S. Department of Agriculture. Received for publication November 1, 1937.

<sup>2</sup>Associate Professor of Soils, Oregon Agricultural Experiment Station; Horticulturist U. S. Dept. of Agriculture; and Laboratory Assistant, Oregon Agricultural Experiment Station, respectively.

<sup>3</sup>Figures in parenthesis refer to "Literature Cited", p. 96.



and the redox potential determined according to the method of Bradfield and associates (1).

In some cases soil samples were taken and suspended immediately in the  $H_2SO_4$  solution in the field. Other samples were brought to the laboratory and later prepared for study. The results were practically the same with the various methods of handling.

Both plate and stiff wire electrodes of bright platinum were used. The electrodes were carefully cleaned in nitric acid, ammonia, and cleaning solution, and checked against each other. They were then left to age in a soil suspension until readings were to be taken. The pH was determined with quinhydrone and samples were checked a number of times.

The cell used for the redox measurement was:

$Hg | Hg_2Cl_2(S) KCl (sat) || \text{soil suspension} | Pt.$

The basic equations for obtaining the potential are:

$$E_h = E_o + \frac{RT}{nF} \ln \frac{(\text{oxidant})}{(\text{reductant})}$$

$$E_t = E_h - E_{cal.}$$

$E_t$  = Total E.M.F. measured.

$E_{cal.}$  = E.M.F. of calomel half cell.

$E_h$  = Oxidation of reduction potential.

The theory of measurement of oxidation-reduction potentials is discussed by Brown (2), also by Peech and Batjer (6) and others (1, 3, 8, 9).

## RESULTS OF STUDY

Some of the soils under study possess tight subsoil horizons. The redox potential on the different horizons does not vary much as indicated by the data of Table 1, which gives the oxidation-reduction potential for an Amity clay loam taken from a Persian walnut orchard on April 14, 1936. This soil was sampled again the last of April and once more the middle of May, and the redox determinations did not show any appreciable change in the oxidation-reduction potentials for any of the horizons and therefore the data are not given. Apparently, oxidation-reduction processes, if active in any horizon of this soil, did not result in a low potential, as indicated by present methods of measurement.

TABLE 1.—*Redox potentials of an Amity clay loam soil, sampled April 14, 1936.*

Soil horizon, inches	E.M.F., volts	pH	$E_h$ volts	$E_h$ @ pH 3, volts*
0-6.....	0.50	2.3	0.75	0.69
6-12.....	0.50	2.4	0.75	0.70
12-24.....	0.50	2.3	0.75	0.69
24-36.....	0.51	2.3	0.76	0.70
36-48.....	0.50	2.5	0.75	0.71
48-60.....	0.48	2.5	0.73	0.69
60-72.....	0.50	2.3	0.75	0.69

\*80 m.v. per pH was used to correct the  $E_h$  to pH 3.0. This value was used by Bradfield and associates (1). When checked in our work the 80 m.v. of Bradfield rather than the standard 59 m.v. proved correct.

A number of productive, moderately productive, and nonproductive orchard soils were studied to determine the differences in the oxidation-reduction potential of the different soils and the different horizons of the same soil. The data for the redox potentials,  $E_h$  at pH 3.0 of these soils and horizons, are given in Table 2. These data show that there was no outstanding difference in the oxidation-reduction potentials in any of the soils or horizons studied, even in the case of the Wapato soil which was sampled from an area which was wet at the time of sampling and which is known to remain in that condition throughout most of the season. The redox potential was practically the same as the well-drained and aerated horizons of the Newberg or Willamette soils. Peech and Boynton (5) find that active forms of manganese concretions in the soil cause rapid oxidations and thus prevent low redox potential readings in poorly drained subsoils.

TABLE 2.—*The redox potentials in volts,  $E_h$  at pH 3.0, of different horizons of seven soil series.*

Soil horizon, inches	Melbourne	Salkum	Newberg	Carlton	Willamette	Chelalis	Wapato
0-6 . . . . .	0.58	0.65	0.64	0.67	0.74	0.72	0.70
6-12 . . . . .	0.64	0.66	0.68	0.69	0.71	0.60	0.65
12-24 . . . . .	0.64	0.65	0.67	0.71	0.75	0.74	0.73
24-36 . . . . .	0.72	0.65	0.69	—	0.74	0.73	0.74
36-48 . . . . .	0.63	0.65	0.74	0.72	0.72	0.72	0.72
48-60 . . . . .	0.67	0.67	0.74	0.63	0.76	0.75	0.76
60-72 . . . . .	0.64	0.68	0.73	0.72	0.76	0.75	0.75
72-84 . . . . .	0.62	0.69	0.70	0.73	0.76	0.73	—

Samples of a Newberg sandy loam were treated with different materials according to the plan given in Table 3. These samples were watered at different rates and incubated for a varying number of days at room temperature. The samples containing both the 75 and 100% moisture contents were water-logged. This Newberg soil normally has a redox potential of 0.70 volt plus or minus. The data indicate that 35% moisture produced enough water logging to result in reduction by dextrose. Reduction occurred in the presence of straw and alfalfa with heavy watering, but not with 25% moisture. The 35% moisture did not cause reduction except in the presence of dextrose.

The limestone does not appear to have a significant effect in any case. Waterlogging in the presence of fresh organic matter appears responsible for whatever changes occur. There is no consistent difference in the effect of low protein material such as straw and the higher protein material such as alfalfa. Such reductions as may occur in the field under reducing conditions which may prevail temporarily, disappear as the soil dries. This is indicated by the oxidations indicated in Table 3 as the soil slowly dried in the laboratory.

#### DISCUSSION

The data indicate that while there may be some difference in the degree of oxidation of various western Oregon soils, the difference is not marked. The climate of western Oregon is such that the moisture of the root zone is well removed by plants during the growing season.

TABLE 3.— $E_h$  at pH 3.0 in volts on Newberg sandy loam, A series in duplicate, B and C series singly.\*

A Series						
Soil treatment	Water %	After incubation for				
		5 days	17 days	26 days	37 days	
1. $\text{CaCO}_3$ +Dextrose, 1%	35	0.57	0.54	0.49	0.56	
2. $\text{CaCO}_3$ , 1%	35	0.57	0.55	0.53	0.49	
		0.74	0.65	0.70	0.68	
3. Dextrose, 1%	35	0.71	0.66	0.70	0.73	
		0.58	0.52	0.46	0.50	
		0.58	0.55	0.48	0.50	
B Series						
Soil treatment	Water %	After incubation for				Dried 22 days
		5 days	12 days	21 days	33 days	
1. Ground alfalfa, 3%	75	0.49	0.49	0.45	0.43	0.54
2. $\text{CaCO}_3$ , 1%+ Alfalfa, 3%	75	0.50	0.49	0.47	0.42	0.55
3. $\text{CaCO}_3$ , 1½%+ Alfalfa, 7%	100	0.50	0.45	0.42	0.39	0.57
4. Ground straw, 3%	100	0.53	0.52	0.46	0.45	0.60
5. $\text{CaCO}_3$ , 1½%+ Straw, 3%	100	0.51	0.55	0.42	0.39	0.58
6. $\text{CaCO}_3$ , 1½%+ Straw, 3%	100	0.45	0.46	0.42	0.39	0.57
C Series						
Soil treatment	Water %	After incubation for				
		5 days	19 days	26 days	33 days	
1. $\text{CaCO}_3$ , 1%	25	0.70	0.74	0.70	0.71	
2. $\text{CaCO}_3$ , 1%+Straw, 3%	25	0.73	0.72	0.65	0.69	
3. Straw, 1½%	25	0.68	0.71	0.66	0.64	
4. $\text{CaCO}_3$ +Alfalfa, 1½%	25	0.70	0.70	0.67	0.68	
5. Alfalfa, 1½%	25	0.75	0.69	0.66	0.66	

\* $E_h$  at pH 3.0 on this soil was 0.70 volt  $\pm$  before any reduction occurred.

The fall rains carry oxygen-laden moisture gradually deeper into the soil. Conditions are favorable, therefore, at certain periods of the year for oxidation processes which produce an oxidized condition in most of the soil types used for agriculture.

The conclusion seems justified that waterlogging may exist in tight subsoil layers without any very active reduction taking place. There is little organic matter in the subsoil, and biological action is limited. A study of the distribution of micro-organisms in the soil profile of these soils in the field indicates that most of the bacteria and fungi are in the top 12 to 24 inches of soil which in all cases is fairly well

aerated. The easy access of air (oxygen) to the surface horizons where fresh organic matter and micro-organisms are present largely prevents reduction of the soil mass in this area. In the deep soil where oxygen may be excluded at times, reduction is not active because of lack of fresh organic matter and organisms.

That the combination of fresh organic matter and waterlogging may bring about reduction is indicated by the data of Table 3. The data indicate that low potentials are obtained only while waterlogging occurs. When there is no waterlogging, decomposition occurs without marked lowering of potential. A reduced soil left to dry regains its oxidized condition in the course of time. The rate of recovery may be slow, however.

Reducing conditions which may exist in the soil are unfavorable to plant growth regardless of whether or not a low redox potential is produced. The well drained, aerated and oxidized soils supply oxidizing conditions and incidentally high potentials. Such a condition is favorable to plant growth. This conclusion is based upon the growth of plants in the field where the soil samples were obtained.

Reduced soils may occur under natural conditions, but cultivated soils of western Oregon studied thus far have not shown a low potential. Yet oxidizing conditions in the soil are essential to those processes, such as nitrification, sulfonation, and others, which prepare plant nutrients for root absorption. There can be little doubt as to the importance of oxidizing conditions in the soil for plant growth.

Peech and Batjer (6) state that practically no reduction occurs in the spring until the soil reaches a temperature of 55° F. Under western Oregon conditions by the time the soils have warmed sufficiently, rains have stopped and waterlogging, except in the subsoil, has disappeared. With aerobic conditions in the zone of humus accumulation, and with biological action, there is perhaps little cause for active reduction processes.

The possibility of an oxidizing agent in the soil, as suggested by Peech and Boynton (5), which is activated by treatments made in the process of determining the oxidation-reduction potential must not be overlooked. The state of reduction of the soil because of inadequacy of methods used under such conditions would not be correctly interpreted. That there are soils of low oxidation-reduction potentials is without question, but the use of present methods in distinguishing waterlogged horizons has been disappointing. Likewise it has not been possible in this study to distinguish the less productive from the more productive soils.

#### SUMMARY

1. Different soil types under field conditions have shown little variation in oxidation-reduction potentials with the methods used.
2. Different horizons of the soil, even where there is a tight subsoil, show little variation in oxidation-reduction potential.
3. Fresh organic matter alone in moist soil does not cause a fall in the potential.
4. Fresh organic matter with a waterlogged condition causes a rapid fall of potential.

5. The oxidation-reduction potential is not a dependable indication of anaerobic conditions in the soil.

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## THE EFFECT OF APPLICATIONS OF COMMON SALT UPON THE YIELD AND QUALITY OF SUGAR BEETS AND UPON THE COMPOSITION OF THE ASH<sup>1</sup>

J. G. LILL, S. BYALL, AND L. A. HURST<sup>2</sup>

FOR many years farmers have been interested in results from salt applications to sugar beets. Tests conducted by Brock (1)<sup>3</sup> showed that, in several years of trial, the use of salt had increased stand, yield, and sucrose percentage over the results from comparable areas not receiving salt. In these tests, commercial fertilizers were used with and without salt, and in some cases only salt was applied. As a result of this report many Michigan beet growers, especially in that portion of the state where salt could be secured cheaply and in quantity, have applied salt to the soil each year for their sugar beet crop. No accurate figures can be obtained as to the acreage treated, nor the total amount of salt used, although both of these totals are known to be large.

Agricultural literature contains many references to experiments with salt as a soil amendment on many different crops. Townsend, cited by Saylor (6), reported Michigan tests in which a 200-pound-per-acre application of salt had increased the yield of beets from 8.69 tons per acre to 11.18 tons. Other Michigan tests of the same general nature are on record.

In 1909, Mette (5) found that, "The yield of beets on plots receiving salt was increased 2,312 kg. per hectare (about 2,058 pounds per acre) over the yield on the plots not so treated. The average sucrose content of the beets on the plots receiving salt was 21.48 per cent as compared to 20.58 per cent for the beets on the check plots."

De Ruijter de Wildt and Mol (2) observed that, "In a third test, sugar beets were grown on land that had been flooded with sea water and contained, as shown by analysis, 35,000 kg. of common salt per hectare to a depth of 60 cm. The composition of these beets showed that the salt content of the soil had reduced the sugar content, changed the relationship of potassium and sodium by greatly increasing the sodium content, and had increased the chlorine and ash content."

In 1915, Tottingham (7) found that soil cultures of sugar beets in greenhouse where sodium chloride was supplied have exceeded the control in yield. Also, in plat experiments in the field with sugar beets at Madison, Wis., an increase in yield was secured by the use of sodium chloride.

<sup>1</sup>Contribution from the Farm Crops Section of the Michigan Agricultural Experiment Station, East Lansing, Mich.; the Carbohydrate Research Division, Bureau of Chemistry and Soils; and the Divisions of Soil Fertility Investigations and of Sugar Plant Investigations, Bureau of Plant Industry, U. S. Dept. of Agriculture, cooperating. Received for publication November 6, 1937.

<sup>2</sup>Associate Agronomist, Division of Sugar Plant Investigations, Bureau of Plant Industry; Assistant Chemist, Carbohydrate Research Division, Bureau of Chemistry and Soils; and Biochemist, Division of Soil Fertility Investigations, Bureau of Plant Industry, respectively. Acknowledgment is due A. W. Skuderna, formerly of the Division of Sugar Plant Investigations, and J. C. Keane, formerly of the Carbohydrate Research Division, for suggestions concerning the conduct of the experimental work upon which this report is based.

<sup>3</sup>Figures in parenthesis refer to "Literature Cited", p. 106.

In 1921, Hoffman (3) wrote, "Common salt and generally most sodium salts increased the quantity and quality of the sugar-beet crop on both light and heavy soils where only light applications of potash had been made and heavy sodium fertilization had been practiced." And: "It was found that the use of sodium reduced evaporation and increased the water-holding power of the soil. It is also thought that through an exchange of bases it is capable of rendering certain relatively insoluble nutritive salts more available to the plants."

In 1936, Egorov (4) reported a resumé of the Charkower Agricultural Technical School field experiments from 1917 to 1935 concerning the action on beets of sodium chloride and manganese sulfate in addition to complete mineral fertilization. According to this resumé, in 14 out of 18 years, the use of sodium chloride increased the yield. The average increase for the use of the sodium chloride was reported as 32.6% for the weight of roots and 38% for the amount of sugar produced per surface unit area.

In 1930, the Michigan State Agricultural Experiment Station and the U. S. Dept. of Agriculture began experiments to determine the effects on the sugar beet crop of applications of common salt. In these experiments salt of "water-softener" grade was used.<sup>4</sup> Beginning with the 1934 experiments, juice from the beets produced under the various treatments was analyzed by the Carbohydrate Research Division, Bureau of Chemistry and Soils, to determine the effect of the salt applications upon the various constituents of the ash of the sugar beet. This work has now been carried to such a point that report is desirable.

#### EXPERIMENTAL RESULTS<sup>5</sup>

In 1930, as part of the extensive series of fertilizer trials on the O'Keefe farm of the Michigan Sugar Company, near Saginaw, Mich., salt was applied at the rate of 500 pounds per acre to certain plats in this experiment. These plats were in systematic arrangement, four plats being end to end and each of these four plats receiving the same treatment whether it were fertilizer alone or fertilizer with salt in addition. On either side of these sets of four plats, which received salt or salt and fertilizer, were check plats also in sets of four and end to end. The results secured on these sets of plats have been averaged for each treatment and for the two sets of check plats, independently, and are presented in Table 1. No attempt has been made to calculate any statistical factors for these results.

Due to the systematic arrangement of the plats in this experiment, it is better to regard the results as having been secured from individual plats for each treatment, although all values were determined for each plat of each treatment separately and the results averaged to determine the effect of the treatment. From the comparisons with

<sup>4</sup>Results of an analysis of a typical sample of this grade of common salt were as follows: Sodium chloride, 96.64%; moisture, 0.20%; undetermined, 3.16.

<sup>5</sup>In agricultural practice, salt is broadcast and harrowed into the soil prior to planting. This method was followed in 1931 when the salt was applied in bands of definite width crossing the field. For the other experiments, the salt was broadcast by hand on the surface of the soil at the specified rates immediately following planting. Commercial fertilizers were drilled in with the seed except for the 1936 test, in which the fertilizer was broadcast by hand in the same manner as the salt after the plats were planted.



TABLE 1.—*Effect of salt applications with and without fertilizer on the sugar beet crop on the O'Keefe farm, Saginaw, Mich., 1930, with the results given as four-plot averages.*

Amount and kind of materials applied per acre	Commercial roots, per acre, no.	Acre-yield of roots, tons	Sucrose %	Apparent purity co-efficient	Calculated sugar production per acre, lbs.*	
					Gross	Indicated-available
Nothing.....	10,839	5.946	19.26	87.57	2,290	2,006
300 lbs. 4-12-4 fertilizer.....	14,553	10.154	19.64	86.07	3,989	3,441
300 lbs. 4-12-4 fertilizer and 500 lbs. salt.....	15,239	11.103	19.55	86.43	4,307	3,725
300 lbs. 4-4-12 fertilizer.....	14,389	8.719	19.06	87.26	3,323	2,900
300 lbs. 4-4-12 fertilizer and 500 lbs. salt.....	15,765	11.557	19.48	87.72	4,503	3,948
500 lbs. salt.....	13,948	9.349	19.70	86.60	3,683	3,187
Nothing.....	9,628	6.328	19.60	86.63	2,481	2,149

\*The results shown are the averages of the values, determined individually, for the four plots of each set, hence differing slightly from the product of the means shown in the table.

the untreated plats lying on either side of the sets receiving salt alone and with the plats that received both salt and fertilizer lying immediately adjacent to a plat that received only the fertilizer, it seems evident that the application of salt to the soil for the sugar beets had a marked beneficial effect upon the crop.

Accordingly, in 1931, the experimental work with salt was carried out on a larger scale. As in the previous year, this work was combined with an extensive series of fertilizer tests and was located not only upon the O'Keefe farm of the Michigan Sugar Company but also upon the Merrill farm of the Holland-St. Louis Sugar Company. In both these series of tests, a number of plats, lying in pairs, received identical treatments. There were 20 such pairs in the series on the O'Keefe farm and 13 on the Merrill farm. One plat of each pair was an unfertilized check, while the other plat received an application of a 4-12-4 fertilizer at the rate of 300 pounds per acre. The fertilized plats and the check plats were divided into four sub-plats, every other sub-plot receiving salt at the rate of 500 pounds per acre. Thus half of the area of each plat in this series was salted.

Salted sub-plats of each unfertilized plat lay immediately adjacent to salted sub-plats of each fertilized plat and the unsalted sub-plats were likewise immediately adjacent to each other. In determining the influence of the application of salt upon the results, the values for the salted sub-plats of each plat were totalled for a comparison with the total of the values of the unsalted sub-plats.

While such an arrangement of plats is entirely systematic, the results are admirably suited to a determination of their statistical reliability by Students' method of paired comparisons. Such deter-



minations have been made for the results secured from the salted and unsalted sections of both the check plats and those plats receiving the 4-12-4 fertilizer. These determinations, however, have been made only for the calculated gross-sugar production.

Table 2 gives the results secured in 1931 in summary form, together with the statistical reliability of the calculated gross-sugar production indicated.

TABLE 2.—*Effect of salt applications with and without fertilizer on the sugar beet crop, O'Keefe farm, Saginaw, Mich., and the Merrill farm, Merrill, Mich., 1931.*

Amount and kind of materials applied per acre	Commercial roots per acre, no.	Acre-yield of roots, tons	Sucrose %	Apparent purity coefficient	Calculated gross sugar produced per acre, lbs.*	Odds that salt had favorable effect
O'Keefe Farm						
No commercial fertilizer applied:						
500 lbs. salt...	18,249	15.212	15.55	84.42	4,721	
Without salt...	17,470	13.514	15.56	84.95	4,208	
Difference§	779	1.698	-.01	-.53	513	9,999 to 1†
Commercial fertilizer applied:						
300 lbs. 4-12-4 plus 500 lbs. salt.....	19,729	16.580	15.77	84.65	5,224	
300 lbs. 4-12-4 only.....	19,901	16.197	15.44	85.14	5,005	
Difference§	-172	0.383	0.33	-0.49	219	31 to 1‡
Merrill Farm						
No commercial fertilizer applied:						
500 lbs. salt...	11,171	11.107	13.00	82.57	2,878	
Without salt...	9,749	9.214	13.42	82.91	2,475	
Difference§	1,422	1.993	-0.42	-0.34	403	830 to 1‡
Commercial fertilizer applied:						
300 lbs. 4-12-4 plus 500 lbs. salt.....	11,905	12.394	13.24	82.38	3,265	
300 lbs. 4-12-4 only.....	11,141	10.894	13.60	83.61	2,950	
Difference§	764	1.500	-0.36	-1.23	315	226 to 1‡

\*The results shown are the averages of the individual plat values, hence differ slightly from the product of the means shown in the table.

†Based on 20 paired plats.

‡Based on 13 paired plats.

§Differences unfavorable to salt are indicated by minus sign.

While the benefit derived from the application of salt to the soil for the sugar beets in 1931 is not nearly so marked as the benefit that had been secured in 1930, the effect of the salt was positive and definite. It is very interesting to note that the influence of the salt applied to the fertilized plats was less in actual amount and less in consistency than where the salt had been applied to unfertilized soil, the consistency of the comparison differences being shown by the size of the odds that the salt had had a beneficial effect.

Although this work was carried on during the seasons of 1932 and 1933, unfavorable conditions and other factors rendered the results worthless.

In 1934, the work was continued in the form of a 5 x 5 Latin square on the Merrill farm of the St. Louis Sugar Company (leased from Holland-St. Louis Co.). Variations in the amount of salt applied were used for the first time for a comparison of the effect of the various amounts applied as well as a comparison with the results secured without any salt. No fertilizer was applied to the soil where the experiment was conducted. The results secured in this experiment were evaluated according to the principles of the analysis of variance and are shown together with the statistical factors determined in Table 3.

TABLE 3.—*Effect of salt applications on sugar beets, Merrill farm, Merrill, Mich., 1934, with the results given as five-plat averages.*

Amount of salt applied per acre, lbs.	Commercial roots per acre, no.	Acre-yield of roots, tons	Sucrose %	Apparent purity coefficient	Calculated sugar production per acre, lbs.*	
					Gross	Indicated-available
None	11,737	7.502	13.03	86.87	1,994	1,739
250	12,126	8.416	12.51	81.90	2,160	1,781
500	13,075	9.264	12.88	82.55	2,402	1,989
750	13,293	9.288	13.04	82.48	2,460	2,044
1,000	14,498	11.220	12.91	83.09	2,904	2,415
Difference required for significance	Not significant	1.605 (1%)†	Not significant	1.31 (1%)†	479 (5%)†	Not significant

\*The results presented are averages of the individual values determined for each of the five plats of each treatment, hence the table will not cross check.

†Values given as required for significance at 1% point indicate that when differences as great as these exist between two averages, the odds are 1 in 100 that so great a difference could have occurred by chance; similarly, when the 5% point is taken, this indicates the odds of chance occurrence as 1 in 20.

The statistical reliability of the above results was greatly diminished by the wide variations in the yield of the individual plats under the various treatments but, when the averages are considered, the yield secured and the calculated gross and indicated-available sugar increased with the increase in the amount of salt applied. The sucrose content of the beets and the apparent purity coefficient were adversely affected, but the application of 250 pounds of salt apparently had as great an adverse effect upon these two factors as the application of 1,000 pounds. The reduction in the sucrose percentage of the beets

and the apparent purity coefficient were not sufficient, however, to offset the favorable effect upon the yield.

The experiment was continued in 1935, but the area was flooded about the time the beets were thinned and the entire stand was lost.

In 1936, the work was expanded to a 6 x 6 Latin square and included, besides the various salt treatments, a set of plats that received an application of 500 pounds of a 2-10-6 fertilizer but did not receive any salt. The results of this test are shown in Table 4.

TABLE 4.—*Effect of salt applications on sugar beets, Merrill farm, Merrill, Mich., 1936, with the results given as six-plat averages.*

Treatment given per acre	Com- mercial roots per acre, no.	Acre- yield of roots, tons	Sucrose %	Appar- ent purity coeffi- cient	Calculated sugar production per acre, lbs.*	
					Gross	Indicated- available
None.....	13,765	8.387	14.91	88.17	2,513	2,185
250 lbs. of salt.....	16,537	11.452	14.52	88.28	3,324	2,938
500 lbs. of salt.....	15,967	12.205	14.86	88.76	3,644	3,230
750 lbs. of salt.....	16,981	13.464	14.80	87.19	3,991	3,479
1,000 lbs. of salt....	16,695	12.537	14.96	87.80	3,777	3,313
500 lbs. of 2-10-6 fertilizer.....	17,012	14.351	15.24	89.43	4,386	3,922
Difference required for significance	1,453 (1%)†	2,129 (1%)†	Not sig- nificant‡	Not sig- nificant‡	712 (1%)†	616 (1%)†

\*The values given for each treatment are the averages of the determinations made on each of the six plats, hence differ slightly from the product of means given in table.

†Values given as required for significance at 1% point indicate that when differences as great as these exist between two averages, the odds are 1 in 100 that so great a difference could have occurred by chance.

‡Variance assignable to treatment did not reach significant amount.

The results secured in 1936, while not entirely in accord with the results that had been obtained in previous years, again demonstrated the favorable effect of the salt applied to the soil upon the sugar beet crop, although the beneficial effect of salt applications is overshadowed by the beneficial effect of fertilizer applied without salt. In 1936 the results were significant for stand, yield, and calculated sugar production per acre, but not significant for sucrose percentage of the sugar beets nor for the apparent purity factor of the sugar beet juice.

When the beets were harvested from the salt test plats in both 1934 and 1936, three samples of 20 beets each were taken from each plat for a determination of the quality of the beets produced. From these samples, a quantity of juice was obtained representing each of the various treatments given. In order to secure this juice so that it would be as representative as possible, each of the three samples from any one plat was pulped and pressed separately and the same amount of juice was taken from each of the three samples to make the final sample of juice representing that certain plat.<sup>6</sup> After the addition of a suitable preservative, the samples of juice were sent to the Carbo-

<sup>6</sup>Acknowledgment is due J. E. Kotila for preparation of the samples used in the 1936 tests.

hydrate Research Division of the U. S. Dept. of Agriculture where a critical analysis of the ash of the juice was made to determine the effect of the application of salt upon the composition of the ash.<sup>7</sup>

In 1934, five analyses were made of the juice of the beets grown on each of the different treatments. In 1936, due to the inclusion of the sixth series of plats that received the fertilizer treatment, the number of analyses made for each treatment was increased to six. The results of the analysis of the ash of the juice of the sugar beets are given in Table 5.

The most important of the changes that occurred in the ash and the only ones that were found to be statistically significant for both 1934 and 1936 occurred in the sodium and chlorine contents. In both years, it was found that the sodium and the chlorine contents increased with the increasing amount of salt applied to the soil, indicating that the greater the amount of salt applied, the greater would be these ash constituents.

There were other changes in the ash constituents, however, that are of interest, even though the results were not found to be significant. With the increasing amounts of salt applied, the total ash was found to increase. This would account in some measure for the lowering of the apparent purity coefficient of the juice of the sugar beets after the application of salt to the soil. The phosphoric acid content of the ash of the beet juice is apparently unaffected by the application of salt but is changed by the application of phosphoric-acid-containing mixtures. This resulted in the data being found significantly different for this constituent in 1936.

But the point that is of greatest interest in the 1936 results, even though the data relating to it were not found to be statistically significant, is the change in the potash content of the ash of the sugar beet juice when salt had been applied in varying amounts and when potash-carrying fertilizer had been applied but with no salt. As the amount of salt applied increased, the potash content of the ash increased in some measure over the potash content of the ash of beets from the untreated plats. This is especially interesting in view of the fact that the potash content of the ash of the beets from the plats that had received an application of potash-carrying fertilizer had not increased perceptibly. The increase in the potash content of the ash that may be credited to the application of the salt ranged from a difference of 0.13 between the untreated and the 250-pound application to a difference of 0.22 between the untreated and the 750-pound application.

There is indication from this that, in comparison with those sugar beets grown with potash supplied directly from the potash-carrying fertilizer, more potash was taken up by the sugar beet from the soil when salt had been applied.

<sup>7</sup>Potassium oxide was determined by a modification of the cobaltinitrite method of Amsterweil and Lemay (Bul. Soc. Chem., 49:1541, 1931); and sodium oxide by the method of Barber and Kolthoff (Jour. Amer. Chem. Soc., 50:1625, 1928). Other determinations were by A. O. A. C. methods as used by the Carbohydrate Research Division in determining ash constituents of white sugars.

TABLE 5.—Results of analysis of the ash of juice of sugar beets grown on the salt-treatment plots, Merrill farm, Merrill, Mich., 1934 and 1936, with the results for 1934 given as five-sample averages and those for 1936, as six-sample averages.\*

Treatment of plots stated on acre basis	Total solids† %	Total ash %	Silicon dioxide %	Sulphur trioxide %	Calcium oxide %	Phosphoric acid %	Chlorine %	Sodium dioxide %	Potash %	Total nitrogen %
1934										
No salt. ....	16.7	3.25	0.19	0.12	0.15	0.18	0.12	0.15	1.51	0.952
250 lbs. of salt.	16.4	3.68	0.10	0.13	0.12	0.19	0.35	0.37	1.65	0.953
500 lbs. of salt.	16.6	3.65	0.11	0.12	0.12	0.19	0.43	0.39	1.57	0.933
750 lbs. of salt.	16.9	3.83	0.13	0.12	0.13	0.17	0.49	0.41	1.59	0.908
1,000 lbs. of salt.	16.7	4.02	0.12	0.11	0.13	0.17	0.58	0.50	1.67	0.878
Difference required for significance	Not significant	Not significant	0.02 (1%)‡	Not significant	0.01 (1%)‡	Not significant	0.08 (1%)‡	0.08 (1%)‡	Not significant	Not significant
1936										
No salt. ....	16.15	3.67	0.04	0.09	0.14	0.15	0.30	0.27	1.61	0.730
250 lbs. of salt.	15.88	4.03	0.04	0.09	0.13	0.14	0.54	0.35	1.74	0.770
500 lbs. of salt.	15.88	4.26	0.03	0.09	0.15	0.15	0.65	0.41	1.78	0.760
750 lbs. of salt.	15.99	4.29	0.03	0.09	0.15	0.15	0.72	0.43	1.83	0.740
1,000 lbs. of salt.	16.16	4.27	0.04	0.09	0.14	0.16	0.70	0.44	1.78	0.760
500 lbs. 2-10-6 fertilizer. ....	16.34	3.57	0.03	0.10	0.15	0.26	0.40	0.24	1.63	0.740
Difference required for significance	Not significant	0.51 (5%)‡	Not significant	Not significant	Not significant	0.01 (1%)‡	0.12 (1%)‡	0.12 (5%)‡	Not significant	Not significant

\*The data for ash, ingredients of the ash, and total nitrogen were calculated to dry substance basis.

†By drying.

‡Values given as required for significance at 1% point indicate that when differences as great as these exist between two averages, the odds are 1 in 100 that so great a difference could have occurred by chance; similarly, when the 5% point is taken, this indicates the odds of chance occurrence as 1 in 20.

## DISCUSSION

With the results of the experiments carried out in practically entire agreement with the results reported by other observers, it must be recognized that common salt when applied to the soil for the sugar beet crop has had, in general, under many different conditions, a beneficial effect. This beneficial effect has been noted on the stand or the number of commercial roots secured, the yield, and, in many cases, on the calculated gross and indicated-available sugar. Sucrose percentages of the sugar beets produced were not significantly influenced in these tests. However, with the apparent purity coefficient of the sugar beet juice, the results have been in the greater number of instances that the ratio is lowered to some extent. This adverse effect upon the apparent purity coefficient has usually not been sufficient to offset the advantage of the increased yield when the amounts of indicated-available sugar have been calculated.

What effect the changes in the ash constituents would have on the refining of the sugar is not known, although it is widely recognized that both the chlorine and the sodium have a marked melassigenic effect. But the application of the salt not only lowered the apparent purity coefficient of the juice of the beets produced but also increased the amount of chlorine and sodium in the ash. It would seem, therefore, that the application of salt to the soil for the beet crop would increase the difficulty of refining the sugar and would also lower the proportion that could be secured.

Since common salt is not recognized as contributing essential plant food material, the beneficial effects noted may be due to a large extent to the effect that salt has upon the plant-food-containing compounds in the soil, making them more available to the beet plants. It might also be pointed out that the benefit derived from the application of salt may be a measure of the need of a certain type of fertilization and that if this fertilization were given directly no benefit would be derived from additional application of salt.

## CONCLUSIONS

It has been found under widely differing conditions that an application of common salt to the soil for the sugar beet crop has had a beneficial effect upon the yield of roots which is reflected, in many cases, as an increase in calculated sugar production.

The application of salt apparently had a detrimental effect upon the apparent purity coefficient of the juice of the beets. Such applications were found to increase the total amount of ash and to increase the proportion of sodium, chlorine, and possibly potassium in the ash. It is judged, from the known properties of the chlorine and sodium in the ash that any increase in these constituents would interfere in the refining of the sugar and reduce the proportion of the sugar that could be recovered.

There is indication that the amount of potash in the ash of the sugar beet juice may have been greater where salt had been applied than where no salt had been applied or where a potash-bearing fertilizer had been used.

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## ADAPTATION OF THE HYDROMETER METHOD TO AGGREGATE ANALYSIS OF SOILS<sup>1</sup>

R. W. GERDEL<sup>2</sup>

THE emphasis that has been placed upon soil aggregation as a significant factor in erosion control indicates the importance of developing suitable methods for studying this physical property of the soil. Among the methods in use for the determination of aggregate-size distribution and the natural structure of soils is the elutriation method used by Baver and associates (1, 2),<sup>3</sup> the wet-sieve method used by Yoder (7), the sedimentation tube of Cole and Edlefsen (6), and the combination wet-sieve and hydrometer method proposed by Bouyoucos (3).

All of these methods are time consuming and limit the number of samples on which analyses may be made. Furthermore, although any of these methods will determine the aggregate-size distribution, none of them will determine the stability of these aggregates. Observations on the residual soils of southeastern Ohio indicate that aggregate stability may be as important as the amount or size-distribution of soil aggregates in any soil erosion investigation.

A method involving the use of the Bouyoucos hydrometer has been developed which permits the determination of certain properties of the soil aggregates. These properties are: (a) The percentage of clay in the aggregated state; (b) the energy required to obtain complete dispersion of the aggregates, or inversely the stability of the aggregates; (c) the dispersibility of the aggregated clay as a result of the application of increasing amounts of mechanical, or chemical and mechanical, energy; and (d) the proportion of the total silt and clay contained in aggregates greater than 0.05 mm.

This method can also be used to determine whether sheet erosion is taking place in the form of texture separates or as aggregates as reported by Yoder (7).

### METHOD

A series of 50-gram aliquots are weighed out from each soil sample and permitted to slake under water for at least 30 minutes. On one aliquot the particle-size distribution is determined by the regular Bouyoucos method (4). Successive aliquots receive 2, 4, 6, 8, and 10 minutes' stirring in the Bouyoucos electric mixer without the addition of any dispersion reagent. If 10 minutes of stirring without the use of dispersing agents does not yield a reading of clay as large as that of the chemically dispersed aliquots, then a series of aliquots receiving a total of 2, 4, 6, or 8 cc of the dispersion reagents are each stirred for 10 minutes. The dispersing solutions, sodium silicate and sodium oxalate, are added in equal amounts. Some one of these treatments will result in complete dispersion of the aggregates.

Another aliquot is transferred to the hydrometer cylinder after slaking and is gently shaken for 2 minutes.

<sup>1</sup>Contribution from the Soil Conservation Service, U. S. Dept. of Agriculture, in cooperation with the Ohio Agricultural Experiment Station, Wooster, Ohio. Received for publication November 8, 1937.

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<sup>3</sup>Figures in parenthesis refer to "Literature Cited", p. 110.



Although it has been found that considerable variation in the amount of shaking may not have any appreciable effect upon the aggregated particles—a phenomenon also reported by Bouyoucos (5)—it appears advisable to treat all samples similarly. Satisfactory results have been obtained by inverting the cylinder at 5-second intervals for 1 ½ minutes, and then at 1-second interval for 30 seconds. Hydrometer readings are then made at 40 seconds and at 1 hour.

### CALCULATION AND INTERPRETATION OF DATA

Table 1 and Fig. 1 show how the data can be employed to calculate some values pertinent to the physical properties of the soil and the susceptibility to erosion.

The differences in the erosive characteristics of the two soils, Belmont silty clay loam and Muskingum silt loam, as observed in the field are substantiated by the aggregate stability curves in Fig. 1. Under intensive cropping, Belmont silty clay loam becomes severely gullied and large areas of this soil have been almost totally destroyed for further agricultural use. Muskingum silt loam, however, is more subject to very severe sheet erosion under intensive cultivation, and gullies of sufficient depth to prevent the use of tillage implements are not as common as on the Belmont soil.

TABLE 1.—Amount and stability of aggregated clay, Muskingum silt loam.

Treatment		Distribution*			Dispersed clay %
Stirring, min.	Reagent, cc	Sand %	Silt %	Clay %	
10	10	19.8	55.8	24.4	100
10	2	—	—	24.4	100
10	0	—	—	23.3	95.5
8	0	—	—	20.3	83.2
6	0	—	—	20.3	83.2
4	0	—	—	19.3	79.1
2	0	—	—	18.3	75.0
Shake		64.5	29.4	6.1	25.0

\*Divisions used by Bouyoucos: Sand, 1.0-0.05 mm; silt, 0.05-0.005 mm; clay, 0.005-0.000 mm

Amount of total clay in water-stable aggregate form =  $100 - \left[ \frac{6.1}{24.4} \times 100 \right] = 75.0\%$

Amount of total silt and clay in water-stable aggregates greater than 0.05 mm =  $\left[ \frac{64.5 - 19.8}{55.8 + 24.4} \right] \times 100 = 55.7\%$

Aggregate stability = 10 min. + 2 cc dispersing reagent, expressed as 10 + 2, or 60% based on Bouyoucos' method = 100%.

The percentage of dispersed clay for each energy interval is calculated on a basis of 100% for the clay found in the completely dispersed aliquot. In Table 1, 24.4% of the soil sample was found to be clay (0.005-0.000 mm). The aliquot receiving 6 minutes' stirring con-

tained 20.3% of dispersed clay, hence  $\frac{20.3}{24.4} = 83.2\%$  of the total clay

content was dispersed by this amount of energy.

The percentage of the total clay content of the soil which is incorporated in water-stable aggregates is determined by dividing the amount of dispersed clay found in the sample which received only shaking by the amount of clay obtained on complete dispersion, and subtracting from 100.

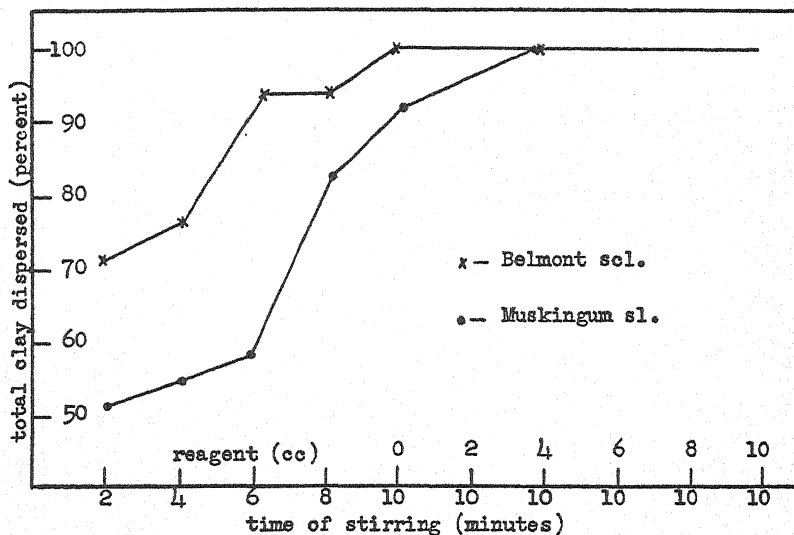


FIG. 1.—Aggregate stability of two residual soils.

The percentage of the total silt and clay contained in water-stable aggregates greater than 0.05 mm is determined by subtracting the sand obtained by complete dispersion from the value obtained for the same size particles by shaking, and dividing by the total silt and clay obtained by complete dispersion.

Since the ultimate stability of the water-stable aggregates is a function of the energy required to obtain complete dispersion of these aggregates, it is possible to compute a numerical value for this stability. The energy value of the Bouyoucos method, prescribing a period of 10 minutes' stirring and the addition of 10 cc dispersion reagents, is taken as an arbitrary maximum of 100%. The actual energy requirements to obtain complete dispersion are then expressed as a percentage of this maximum. If 8 minutes of stirring results in complete dispersion, then  $\frac{8}{10 + 10} = 40\%$  aggregate stability; 10 minutes stirring and 2 cc of reagent would produce aggregate stability of  $\frac{10 + 2}{10 + 10}$ , or 60%.

A slight modification of the method is required where sufficient free electrolytes are present to cause flocculation. The minimum amount of the dispersion reagents required to produce suspension is first determined by adding successive 2-cc portions of dispersion reagents

to an aliquot which has been stirred for 6 or 8 minutes. This minimum amount of reagent required to prevent flocculation is added to each cylinder after stirring is completed. If complete dispersion is not obtained by this means, successive aliquots receive increasing amounts of the reagents before they are stirred for 10 minutes. It has been found that 1 cc of sodium oxalate and 1 cc of sodium silicate are usually sufficient to prevent flocculation.

Interesting data have been obtained by using this method of studying aggregates on different soil types and land use. These data will be reported in a paper now in preparation.

### SUMMARY

A method that employs the Bouyoucos hydrometer for studying water-stable aggregates and aggregate stability is presented. Although this method will not determine the complete aggregate-size distribution, it does permit the study of other properties of water-stable aggregates that are pertinent to studies of erosion control and other problems in soil physics.

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## COMPARISON OF LEGUME GROWTH IN DIFFERENT SOIL TYPES AT VARYING ACIDITY LEVELS<sup>1</sup>

H. L. HYLAND<sup>2</sup>

THE use of legumes for maintaining soil fertility is generally accepted as being of considerable importance, although their use on acid soils has been somewhat limited due to the lack of adaptability of the more commonly used species to such conditions. Wheeler's (7)<sup>3</sup> early study of plants tolerant to soils with low acidity readings and Coville's (1) emphasis on the need for legumes capable of thriving under such conditions have been partially responsible for the development of interest in "acid-tolerant" legumes. Although it is known that certain legumes are acid-tolerant, specific information is lacking on the response of the different species in respect to their tolerance to acid soils, indicated as such by relatively low pH readings.

The studies herein reported were conducted under greenhouse conditions at Arlington Experiment Farm, Arlington, Va., in 1934 and 1936 to determine the variation in growth response of specific legumes when grown in different soil types and at varying pH levels.

### MATERIALS AND PROCEDURE

Korean lespedeza (*Lespedeza stipulacea*), sericea (*Lespedeza sericea*), crown vetch (*Coronilla varia*), and zigzag clover (*Trifolium medium*) were chosen for use in this experiment because of their ability to grow on poor unlimed soils when compared to red clover (*Trifolium pratense*) and sweet clover (*Melilotus alba*). Seedlings of crown vetch, sericea, and zigzag clover in quadruplicate were made on December 18, 1933, and red clover and sweetclover on January 23, 1934, for the 1934 experiment. In 1936 all seedlings were made on March 11 in triplicate.

One-gallon stone jars equipped with drains in 1934 and without in 1936 were used as soil containers. Artificial cultures were used in all cases for inoculating the seed. Subsequent thinning after germination reduced the number of plants per jar to 7 and 13 for the two years, respectively. All jars were arranged at random on the greenhouse bench.

Jars were weighed at frequent evenly spaced intervals and distilled water added to insure proper moisture conditions for optimum growth. Detailed records on growth and all changes in plant appearance were noted. The experiments terminated October 1, 1934, and June 30, 1936, respectively, at which time final growth notes and soil pH readings were taken.

Bladen fine silt loam with an original pH reading of 4.4 was used in 1934, and Ashe stony loam, DeKalb sandy clay loam, and Clement silt loam with original readings of 4.4, 4.8, and 5.1, respectively, were used in 1936. The pH levels of these soils were raised by adding calcium carbonate to the original soil. The "trial

<sup>1</sup>Contribution from the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Received for publication November 8, 1937.

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<sup>3</sup>Figures in parenthesis refer to "Literature Cited", p. 121.

and error" method was used to determine the proper proportions of calcium and soil necessary for readings of approximately 1 and 2 pH above those of the original soils. The readings were made with a quinhydrone electrode as outlined by Snyder (6).

### EXPERIMENTAL RESULTS

Growth differences among the five legumes at progressive dates in 1934 on Bladen fine silt loam and changes in soil pH are shown in Table 1. Variations in growth, first noticeable three to four weeks after planting, are quite evident. In all instances the largest amount and healthiest growth, as judged by consistent gains in height and amount of top and root growth, and the best development of nodules occurred in the pH 5.3 series.

The only appreciable amount of growth in the original soil with a pH of 4.40 was made by sericea and zigzag clover, although red clover made a good start. All the sericea plants remained alive at this pH level until the end of the experiment and the growth nearly equalled that of plants grown at pH 5.30. Zigzag clover showed similar results although a few plants were lost. Considerable trouble was experienced at pH 4.40 with early dying of crown vetch seedlings, necessitating frequent transplanting of healthy seedlings from another source during the first few days after germination, and even these gradually succumbed. Sweet clover plants failed entirely. The number of zigzag clover plants that survived at the 6.40 pH level was three to four times greater than for the other legumes.

The apparent decrease in height of crown vetch at pH of 4.40 and 6.40, and of the zigzag clover plants at 6.40 between January 22 and March 26 is accounted for by the method of measurement. Measurements were made from the base of the stem at the soil surface to the growing tips of the primary leaves. As the seedlings started to die, the primary leaves dropped from the plants and measurements were made to the point of emergence of new growth which was closer to the soil surface than were the tips of the primary leaves. More plants were found dying as the dates of measurement progressed, thus producing a lower average height figure.

After six weeks this dying of plants in the 6.40 series became very apparent. A condition resembling a salt accumulation appeared on the soil surface and upon re-checking the pH reading, it was discovered that through error (limitation of use of the quinhydrone electrode) a large excess of carbonate had been added to the original soil. Between March 26 and April 20, the few plants of all species remaining alive showed an increase in average height, such behavior suggesting that some of the excess carbonate may have been removed through drainage. Midgley (2) has shown that such action occurs.

Between December 1933 and October 1934 the pH readings in the original soil and in that raised to pH 5.30 declined in every case, but an increase of over 1 pH in soils raised to pH 6.40 was shown. This latter change indicates that a large excess of lime was added when originally preparing the pH 6.40 soil.

Results more interesting than those in 1934 were secured in the 1936 tests where Ashe, DeKalb, and Clement soils were used. Growth

TABLE 1.—Differences in plant growth at three pH levels on Bladen fine silty loam for legumes grown in the greenhouse at Arlington Farm, Va., 1934.\*

Soil pH readings			Average height of top growth, cm.					Plant condition Oct. 1, 1934			
Dec. 1933	Oct. 1934	Jan. 22	Feb. 5	Feb. 19	Mar. 5	Mar. 26	Apr. 20	No. live plantst	Average height tops, in.	Average length roots, in.	Nodulation
Crown Vetch											
4.40	4.30	1.48	1.40	1.40	1.23	1.05	1.00	None	—	—	—
5.30	4.81	2.59	2.60	2.15	2.86	5.91	12.40	4.5	20-28	14-24	Good
6.40	7.51	3.21	3.00	2.32	1.87	1.74	3.20	0.8	2-3	Trace	—
Sericea											
4.40	4.13	2.57	3.50	4.10	5.90	12.70	35.50	7.0	42-48	14-18	Good
5.30	4.94	3.05	3.80	5.45	8.84	21.47	49.80	7.0	56-60	18-20	Good
6.40	7.55	2.19	2.40	2.60	2.77	2.97	2.93	1.5	3-5	3-5	Poor
Zigzag Clover											
4.40	4.15	1.78	1.90	2.00	2.68	4.32	6.90	6.5	6-8	8-16	Poor
5.30	4.90	2.25	2.40	3.00	4.62	8.16	11.10	6.8	16-20	14-20	Fair
6.40	7.52	2.26	1.90	1.90	1.77	1.41	1.90	5.3	8-12	4-10	Fair
Red Clover†											
4.40	4.15	—	—	2.10	2.14	3.73	8.40	None	—	—	—
5.30	4.72	—	—	2.75	3.21	8.95	14.70	4.0	10-14	8-10	Poor
6.40	7.50	—	—	2.55	2.32	1.36	3.20	1.0	—	—	—
Sweet Clover‡											
4.40	4.40	—	—	1.25	1.18	1.07	1.30	None	—	—	—
5.30	4.72	—	—	1.70	1.88	3.55	9.40	5.5	34-36	26-28	Good
6.40	7.37	—	—	2.05	1.69	1.82	4.00	1.3	30-32	26-28	Fair

\*Averages for four replicates of crown vetch, sericea, and zigzag clover and two of red clover and sweet clover.

†Seven plants in all jars originally.

‡Planted one month later than crown vetch, sericea, and zigzag clover.

produced in Ashe stony loam was practically negligible regardless of the pH level as shown by the weights of top and root growth in Table 2. Plants of most species made growth for a few days after germination with a slight tendency to do better at the two higher pH levels, but these differences soon disappeared.

The 5 grams of plant material shown for sericea growing at pH 5.44 is the largest amount produced by any species. The figures for Korean lespedeza and sweet clover are similar, most of the weight being supplied by roots. Sericea also shows the highest plant survival at all three pH levels, followed by zigzag clover and Korean lespedeza, although no plants are shown for the latter in the original soil. All sweet clover plants succumbed in the soil with pH 4.40 and in the two limed series where more growth was expected, the number of plants surviving is comparatively small.

The Korean lespedeza, sericea, and zigzag clover plants at the 6.37 pH level lacked green leaf color and many turned yellow, while only zigzag clover lacked green color at pH 5.44. The plants turning yellow dropped their leaves, and either died completely or remained stunted during the entire experiment. The yellowing of these plants might be due to some minor element deficiency. The lack of growth in this soil type is quite evident from the three-months old plants shown in Fig. 1.

In the Ashe stony loam the pH readings in every case were less on June 30 than at the start of the experiment. The greatest change in pH occurred in the jars originally reading pH 6.37.

Differences in amount of growth in DeKalb sandy clay loam at the three pH levels are quite pronounced (Table 2). In spite of very slow germination all species produced excellent growth at the pH 5.95 level and in some instances a fair amount in the 6.72 series, but a complete failure resulted in the original soil at a pH level of 4.40. The number of plants surviving at the two higher levels is similar for the different crops except sericea which shows a perceptible loss.

At pH 4.40 practically every plant in all the crops yellowed and died shortly after germination. At the two higher pH levels small, round, dark spots appeared on all Korean lespedeza and sericea plants particularly on the cotyledon and primary leaves. This condition was most noticeable on the Korean lespedeza plants. As new growth developed, however, only the lower leaves remained affected, and after these had finally fallen the other portions of the plant were more healthy and practically free from the spotted condition. Similar symptoms have been reported as due to potash deficiency (3, 5).

At succeeding later dates, the difference in growth of all crops between the 5.95 and 6.72 levels became greater. Comparison of the three-months old plants of the four crops may be made from Fig. 2. Attention should be called to the normal growth habits of these plants. That of sweet clover is fairly well known, seedling plants under favorable conditions making a growth of 2 to 3 feet the first season, with the stems conspicuous and comprising a large portion of the plant weight. Sericea plants may grow to 3 feet in height the first year and produce a higher percentage (by weight) of leaves than sweet clover. Korean lespedeza and zigzag clover, however, possess finer stems and



produce a more spreading and shorter type of growth. Zigzag clover is a more prostrate grower than Korean lespedeza.

The largest amounts of growth were obtained at the 5.95 level. Sweet clover showed the largest combined plant weight with a total of 70.7 grams for stems and roots. Considering the growth habits, zigzag clover with an average of 57.3 grams and Korean lespedeza with 53.4 grams both compare favorably with sweet clover in amount of growth. Sericea shows the smallest total plant weight with 38.4 grams.

Soil pH readings

4.40

5.44

6.37

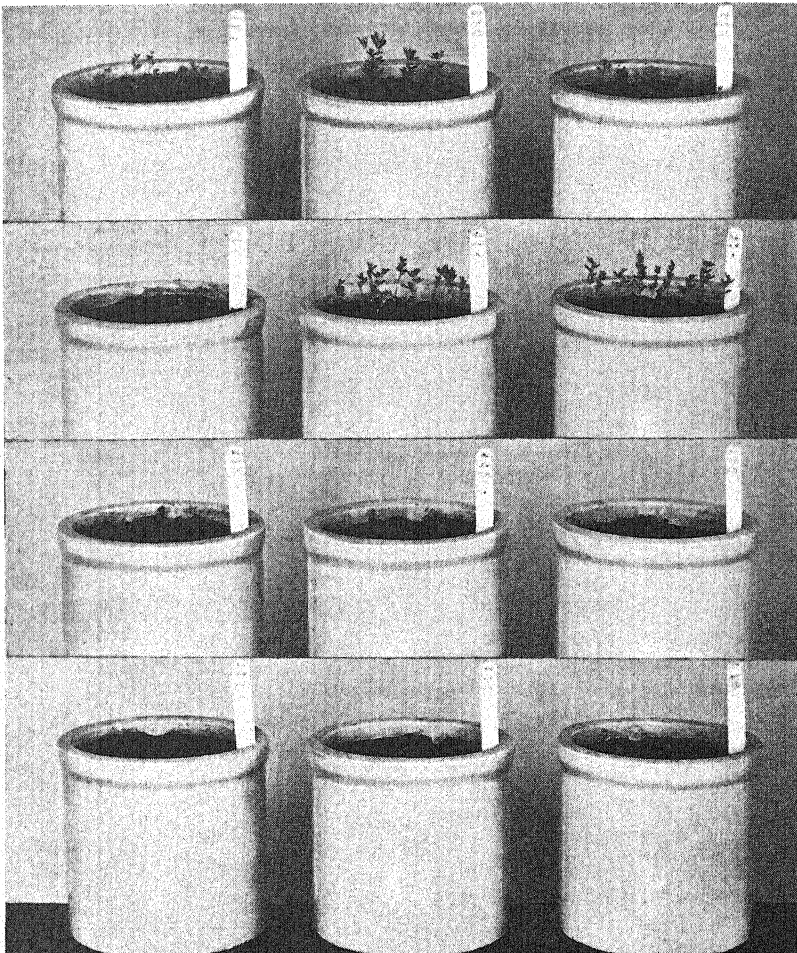


FIG. 1.—Comparative growth of three-months old legume plants in three pH levels of Ashe stony loam. From top to bottom, sericea, Korean lespedeza, zigzag clover, and sweet clover.



TABLE 2.—Differences in plant growth at three pH levels on three acid soil types for legume plants grown in the greenhouse at Arlington Farm, Va., 1936.\*

Ashe stony loam					DeKalb sandy clay loam					Clement silt loam				
Soil pH readings		Growth record 6/30			Soil pH readings		Growth record 6/30			Soil pH readings		Growth records 6/30		
May 11	June 30	No. live plantst	Tops, gramst	Roots, gramst†	May 11	June 30	No. live plantst	Tops, gramst	Roots, gramst†	May 11	June 30	No. live plantst	Tops, gramst	Roots, gramst†
Korean Lespedeza														
4.40	4.29	None	—	—	4.80	4.04	None	—	—	5.10	4.68	13.0	11.3	19.3
5.44	5.12	12.3	1.7	3.0	5.95	5.42	11.7	30.7	22.7	6.13	5.32	13.0	15.3	13.7
6.37	5.69	10.7	1.0	—	6.72	5.88	11.7	17.3	12.3	7.09	6.30	12.7	16.0	12.3
Sericea														
4.40	4.31	9.7	1.0	0.7	4.80	4.07	None	—	—	5.10	4.69	12.0	10.3	10.3
5.44	4.97	12.3	2.3	2.7	5.95	5.28	8.7	22.7	15.7	6.13	5.30	12.7	12.3	10.7
6.37	5.68	12.3	1.0	—	6.72	5.74	6.0	8.3	6.0	7.09	6.18	11.7	12.0	7.7
Zigzag Clover														
4.40	4.34	3.3	1.0	—	4.80	4.08	1.0	—	—	5.10	4.73	13.0	5.3	7.3
5.44	5.03	12.3	1.3	0.7	5.95	5.33	12.0	34.3	23.0	6.13	5.39	12.3	11.0	16.7
6.37	5.80	12.3	1.0	—	6.72	5.79	10.3	15.0	8.7	7.09	6.42	12.0	12.3	14.7
Sweet Clover														
4.40	4.33	None	—	—	4.80	4.05	None	—	—	5.10	4.72	12.7	1.3	2.7
5.44	5.07	4.3	1.0	3.0	5.95	5.44	10.3	20.7	50.0	6.13	5.37	11.3	5.7	11.3
6.37	5.76	4.0	1.0	—	6.72	6.03	10.7	19.7	32.3	7.09	6.52	12.0	8.3	9.7

\*Averages for three replications.

†Thirteen plants in all jars originally.

‡Weights are of the green material.

At pH 6.72, sweet clover produced top growth equal to that in the 5.95 pH series, but less root weight. Korean lespedeza and zigzag



FIG. 2.—Comparative growth of three-months old legume plants in three pH levels of DeKalb sandy clay loam. From top to bottom, sericea, Korean lespedeza, zigzag clover, and sweet clover.

clover with averages of 29.6 and 23.7 grams, respectively, approximated only half the amount of plant material produced at pH 5.95. The growth of sericea compared rather poorly with that of the other crops at the pH 6.72 level, or with the material produced by it at the next lower pH level.

Decreases in pH in the DeKalb soil are least in the soils of the 5.95 pH series or where the most plant growth is shown to have occurred. Changes in the original soil with a pH of 4.80 and in that raised to pH 6.72 were similar, ranging from 0.69 to 0.98 pH.

The uniformity of plant growth in Clement silt loam (Table 2) presents a contrast to that produced in the Bladen, Ashe, and DeKalb soils. The survival of plants is high and similar regardless of the crop or degree of soil acidity. In amount of growth, Korean lespedeza produced the most uniform average weights, showing 30.6, 29.0, and 28.3 grams, respectively, for the three pH levels. Zigzag clover shows 27.7 and 27.0 grams, respectively, for the two higher levels, but produced only 12.6 grams of material in the original soil. Fig. 3 shows the comparative three-months old growth of the four species.

Probably the most interesting observation, as shown in Table 2 and Fig. 3, is that sweet clover produced less material in proportion to its normal growth than the other three legumes. It also produced the poorest growth of all the crops in the original soil, followed closely by zigzag clover.

The average decreases in pH were 0.40, 0.79, and 0.74 for the original soil and two succeeding higher levels, respectively.

Attention is called to the weights of plants in this soil and to that of plants in the DeKalb sandy clay loam at pH 5.95. Since the growth as shown in Figs. 2 and 3 was quite similar, plant weights would also be expected to be similar. The lower weights of the plants in the Clement silt loam can be partially accounted for by the fact that red spider infestation was heavy, and by the time final weights were recorded many leaves had been lost.

#### DISCUSSION

From the data presented, variable and highly significant growth differences have been found to occur, not only among the legume crops tested but also in the four acid soil types used. The conditions under which these differences were found indicate quite definitely that a certain expected amount of growth cannot be correlated with specific soil pH readings. Results show that plant species, soil type, and addition of lime were, in a measure, responsible for growth differences.

Growth responses in the different soil types varied with the crop. The so-called acid-tolerant plants, as a group, were more successful at the lower pH readings than sweet clover, and in some cases produced as much or more material at the higher pH levels. This was particularly true of sericea which made good growth in the original Bladen and Clement soils, while sweet clover made only a fair showing in the latter. Red clover, grown only in the Bladen soil, proved less responsive at each corresponding pH than any of the acid-tolerant plants or sweet clover. Where the plants were grown at readings approximately 1.0 pH higher than the originals, sericea produced

more growth than sweet clover in the Bladen, Ashe, and Clement soils and practically the same amount in DeKalb. In the heavily

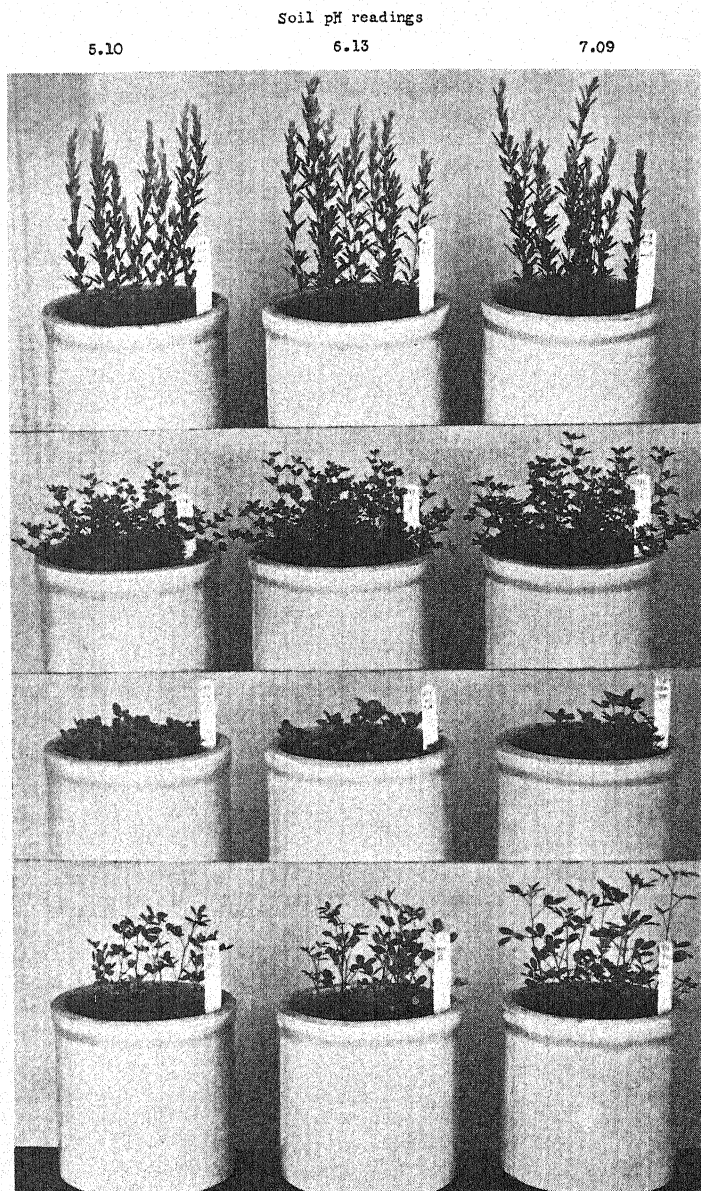


FIG. 3.—Comparative growth of three-months old legume plants in three pH levels of Clement silt loam. From top to bottom, sericea, Korean lespedeza, zigzag clover, and sweet clover.

limed series, however, sweet clover produced the most growth in the Bladen and DeKalb soils.

It is interesting to note that certain variations have occurred in the acid-tolerant group of plants showing differences in possible degree of tolerance. In the unlimed jars, Korean lespedeza, sericea, and zigzag clover plants on the Clement type made relative growth in the order named. Only the latter two were able to produce any semblance of growth in the Bladen and Ashe soils, with sericea showing a little advantage in plant survival and amount of growth. Crown vetch failed in its only trial in the Bladen soil. In the higher pH levels where calcium carbonate had been added, except in Ashe stony loam where practically no growth was made, a few differences were noted in amounts of growth giving the advantage to one species over another in the same pH level.

It appears that the differences in growth noted in the various crops can be accounted for only by the variation in adaptability of these specific legumes to acid soils since they were grown under controlled conditions.

The wide variations in plant growth secured with a difference of only 0.7 pH for the four soils in their original state strongly indicate that factors other than pH affect crop adaptation to acid soils. While some unknown condition unfavorable for plant growth apparently existed in the Ashe soil even at higher pH levels where lime had been added, similar conditions, as measured by plant response, were present in the Bladen and DeKalb soils. The addition of lime to the latter soils produced more favorable plant growth, although the highest pH series produced less growth than the intermediate pH lots. This inhibition of growth may have been due to overliming of acid soils (4).

Plant growth, as correlated with the use of lime to produce the various pH levels, failed to show consistent results. Changing the readings of the Bladen and Ashe soils from 5.30 and 5.44 to the next higher pH, respectively, failed to increase the amount of growth. The same was true in DeKalb, except the growth at the higher pH was good when compared to that of the above two soils. In the Clement soil, however, increasing the alkalinity brought significant growth increases for three of the four species under study.

From these results it would seem that liming to correct acid conditions may not always prove a solution for bettering plant growth, if changes in pH are to be the basis for judging such corrections, and any statement to the effect that certain legumes will grow best in a soil of a specific acid reaction can easily be misleading.

#### SUMMARY

Korean lespedeza, sericea, zigzag clover, and crown vetch plants, which usually grow well on poor, unlimed soils and red clover and sweet clover plants which are more responsive to limed soils, were grown in four soil types under greenhouse conditions and at three pH levels.

Wide variations in growth of the different crops were found to occur when they were grown in different soil types and at different pH levels.

Sericea was a little more tolerant of lower pH readings than Korean lespedeza or zigzag clover while the latter two compared favorably with each other in this respect. Zigzag clover showed a tendency to tolerate a higher alkaline concentration than sericea. Crown vetch failed to grow in a soil of 4.4 pH and gave only a fair growth in the 5.3 level for the same soil. Considering the amount of growth normally produced, Korean lespedeza, sericea, and zigzag clover in many cases made relatively more growth than either red clover or sweet clover, regardless of pH level.

The addition of calcium carbonate to a soil with an original pH reading of 5.10 did not significantly increase the amount of legume growth.

Soil pH readings, as indicated by the above studies, were not true indicators of the adaptation of different legume crops to such soils.

Decrease in soil pH occurred between the start and finish of the experiments in all soil types and different pH levels of these types, except in the 6.4 series of the Bladen fine silt loam where a large excess of calcium carbonate was added through error. The largest decreases occurred where most plant growth resulted and where the largest amounts of lime had been added.

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## EFFECT OF LOCUST TREES UPON THE AVAILABLE MINERAL NUTRIENTS OF THE SOIL<sup>1</sup>

W. H. GARMAN AND F. G. MERKLE<sup>2</sup>

FOR many years the black locust (*Robinia Pseudo-Acacia* L.) has been used in the repair of soils ruined by erosion and mismanagement. Its ability to establish itself on barren subsoils is equaled by but few other plants. Shortly after it is established the site becomes improved to such an extent that other species, in themselves less tolerant to barrenness, are found to thrive. Kentucky bluegrass may be encouraged to grow voluntarily on bare subsoil in association with locust.

Ferguson (1)<sup>3</sup> called attention to the fact that in a catalpa grove adjacent to a locust grove the growth of the catalpas was much better close to the locusts and that it decreased gradually as the distance from the latter increased. He reported, and it was later confirmed by MacIntyre and Jeffries (2) that the nitrogen content of the soil close to the locust grove was higher and that it diminished as the distance increased. Chapman (3) has likewise shown that the growth of catalpa, white ash, tulip poplar, black oak, and chestnut decreased progressively as the distance from the locusts increased. He found that the total nitrogen in the locust grove was 3,900 pounds per acre and only 1,800 pounds outside the influence of the locusts.

In a 25-year-old locust grove in Mason County, Illinois, Gustafson (4) noted in 1934 that the surface of the sand under the locusts was covered with the remains of the locust leaves and some small twigs which had accumulated, and that Kentucky bluegrass (*Poa pratensis*) was well established under the trees, but that it did not gain foothold a short distance away. He attributed the beneficial effect of the trees to the nitrogen and other nutrients, and to better moisture and temperature conditions.

Apparently, quantitative evidence of the nitrogen-accumulating power of the locust has been demonstrated. Its ability to bring available mineral nutrient elements to the surface and to alter the pH value of the soil is not as well known, or at least quantitative data to substantiate this belief are wanting. Of course it is well known that all trees possess this tendency. A measure of the mineral-enrichening function of locusts is reported herewith.

About seven years ago a steep barren road embankment, cut into what is known as the Morrison soil, was planted to locust saplings. This soil, although underlain at considerable depth by dolomitic sandstones is very acid throughout its A and B horizons and the greater part of its C horizon. The B horizon contains a ferruginous clay. Under natural conditions the surface soil grows no bluegrass

<sup>1</sup>Contribution from the Department of Agronomy, Pennsylvania State College, State College, Pa. Authorized for publication on November 4, 1937, as paper No. 794 in the Journal Series of the Pennsylvania Agricultural Experiment Station. Received for publication November 11, 1937.

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<sup>3</sup>Figures in parenthesis refer to "Literature Cited", p. 124.

while the subsoil is the last place one would look for this species. However, it was noted that, after the locust saplings had dropped three or four crops of leaves, bluegrass began to grow spontaneously near the base of the trees where the leaves lodged. In a few years a circular area around each tree trunk about 8 to 18 inches in diameter was covered with feathery locust leaves and spears of bluegrass. It seemed possible that not only the nitrogen fixed by the locusts, but also the available mineral nutrients brought to the surface by the leaves might help explain the volunteer appearance of bluegrass on such an unfavorable site.

To determine if mineral enrichment had taken place, samples were taken, one from within the litter circle and one from the barren embankment a short distance from the trees but where no leaves had collected. In each case the surface leaves and soil were removed and the actual samples taken between the second and fifth inch in depth. Thus no leaf debris was included. Five paired samples were taken at average distances of  $3\frac{1}{2}$  to 4 feet from each other. The samples were quickly dried and analyzed for pH value and for readily available calcium, magnesium, potassium, and phosphate. The latter were extracted with N/4 sodium acetate made to pH 5 and determined by the micro methods. Total nitrogen was not determined as this property had been investigated by other workers. The results are reported as pounds in 2 million pounds of dry soil. The data are presented in Table 1.

TABLE 1.—*Readily extractable mineral nutrients in soil as influenced by locust litter.\**

Lab. No.	Comparison	Ca	Mg	K	PO <sub>4</sub>	NO <sub>3</sub>	pH
2803	Under litter	976	74	150	Trace	30	7.1
2802	Outside	432	60	50	Trace	10	5.4
2998	Under litter	936	84	200	Trace	Trace	7.2
2999	Outside	340	31	100	Trace	Trace	6.3
3000	Under litter	720	101	200	Trace	10	6.6
3001	Outside	208	50	100	Trace	Trace	5.2
3002	Under litter	792	134	150	Trace	10	6.6
3003	Outside	180	55	100	Trace	Trace	5.1
3004	Under litter	888	120	150	Trace	30	5.6
3005	Outside	340	140	100	Trace	Trace	5.0

\*Expressed as pounds in 2 million pounds of dry soil.

The findings are very conclusive. Basic nutrients have been withdrawn from the lower layers and deposited at the surface. The amounts of active calcium, magnesium, and potassium have been significantly increased as a result of the deposition of leaves. The pH value of this subsoil is normally 5.0 to 5.5. The effect of the litter has been to raise the value to close to the neutral point.



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## RECENT STUDIES ON THE GENETICS OF THE SOYBEAN<sup>1</sup>

C. M. WOODWORTH AND L. F. WILLIAMS<sup>2</sup>

IN connection with the investigational work on soybeans being carried on at the Illinois Agricultural Experiment Station in cooperation with the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, the genetics of the soybean occupies a prominent place. Because of the growing interest in this new crop, particularly from the breeding standpoint, it has seemed desirable to present briefly the results of recent genetic studies. This account is divided into two parts, namely, (a) a description of new chlorophyll-deficient types, together with any available data on mode of inheritance, and (b) a discussion of new linkage relationships.

### NEW CHLOROPHYLL-DEFICIENT TYPES

The  $y_4$  type is a yellowish-green type found in F. P. I. 65388, a small-seeded brown bean obtained from the Division of Forage Crops and Diseases, U. S. Dept. of Agriculture. The original lot of seed was treated with radium by Doctor J. T. Buchholz, Botany Department, University of Illinois. The mutant appeared in the progeny of a plant grown from one of these treated seeds. The ratio was 22 normal to 3 yellow. Fifteen of the normal green plants were tested in the greenhouse. Of these, 4 bred true for green and 11 segregated in approximately a 3:1 ratio. The evidence seems clear, therefore, that the mutant is a simple recessive to the normal.

The  $y_5$  type is a greenish-yellow type first observed as a mutant in the Wilson V variety. It bred true from the first. A cross was made with the Virginia variety. Two  $F_1$  plants were produced, both normal green. Of 104  $F_2$  plants, 80 were normal, 24 greenish-yellow. In the  $F_3$  generation, of 36 families grown, 12 bred true for green and 24 segregated in a 3:1 ratio.

Both  $y_4$  and  $y_5$  are weak, although  $y_5$  is the better of the two. They are easily distinguished from each other in appearance. The chlorophyll of  $y_4$  is uniformly reduced, so that the leaf surface has a uniform appearance, while in  $y_5$  there are areas in the leaf of varying chlorophyll intensities. The leaf seems to change from yellow to green and back again as it is turned at various angles to the sun.

In the cross between  $y_5$  and Virginia, two other pairs of genes were involved, namely, Tt (tawny vs. gray pubescence) and  $R_1r_1$  (black vs. brown coat color). The results given in Table 1 indicate independence between these and  $Y_5y_5$ .

<sup>1</sup>Contribution from the Division of Plant Breeding, Department of Agronomy, University of Illinois, Urbana, Ill., in cooperation with the U. S. Regional Soybean Industrial Products Laboratory, U. S. Dept. of Agriculture. Published with the approval of the Director of the Experiment Station. Received for publication November 19, 1937.

<sup>2</sup>Chief in Plant Genetics, Illinois Agricultural Experiment Station, and Agent, Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, respectively.

TABLE 1.—Data showing independent inheritance between  $Y_5y_5$  and  $Tt$  and between  $Y_5y_5$  and  $R_1r_1$ .

F <sub>2</sub> classes	Pubescence color and leaf color				
	TY <sub>5</sub>	Ty <sub>5</sub>	tY <sub>5</sub>	ty <sub>5</sub>	Total
Actual results . . . . .	33	5	18	2	58
Expected results (9:3:3:1) . . . . .	32	11	11	4	58

F <sub>2</sub> classes	Coat color and leaf color				
	R <sub>1</sub> Y <sub>5</sub>	R <sub>1</sub> y <sub>5</sub>	r <sub>1</sub> Y <sub>5</sub>	r <sub>1</sub> y <sub>5</sub>	Total
Actual results . . . . .	43	9	6	1	59
Expected results (9:3:3:1) . . . . .	33	11	11	4	59

Deviations from expected results in Table 1 are due mainly to deficiency of the  $y_5$  segregates.

The  $y_4$  and  $y_5$  types were crossed and produced normal green F<sub>1</sub> plants. Incidentally, much hybrid vigor was apparent in this cross. The F<sub>2</sub> generation segregated in a 9:7 ratio of normal to chlorophyll-deficient plants. Of 186 plants, 112 were green and 74 yellowish. On the basis of a 9:7 ratio, 105 green and 81 yellow would be expected, a deviation of 7 from expectation. From this cross a third type of chlorophyll abnormality is expected, namely, that which is recessive for both  $y_4$  and  $y_5$ . However, on account of the low vigor and sparse seed production of the chlorophyll-deficient segregates, the double recessive could not be distinguished from the  $y_4$  and  $y_5$  types. Since very little seed was obtained from these segregates, progeny tests could not be made. It is hoped that further work with the heterozygous normal segregates will bring about the isolation of the double recessive type.

The  $y_6$  type is a pale green type found in the Rokusun variety of vegetable soybeans. It can be easily distinguished from the normal green in the early plant stage, but later it apparently develops more chlorophyll and to all outward appearance is normal green. It appears to be a simple recessive to the normal. A cross between  $y_6$  and Illinois Type 24A gave 76 green to 20 pale green. Although the pale class is somewhat deficient, this is evidently a monohybrid segregation. The  $y_6$  type was discovered only this past season and no crosses have yet been made with other chlorophyll-deficient types.

The  $y_7$  type is characterized by a distinct yellowing which extends to the leaves, stems, and pods as well as the seeds. The yellowing is first noticeable in the stems and then the leaves, pods, and seeds become progressively yellow. On the leaves it shows first in the veins and these yellow-veined leaves serve to distinguish it readily from other yellow types. This gene has more of a yellowing effect than any other so far discovered, as it affects even the seed coat and cotyledons. In spite of the very pronounced reduction of chlorophyll, this type is fairly vigorous. It was observed in a few vegetable soybeans, but more commonly in F. P. I. 81029. It has not been tested in controlled crosses, but in families segregating naturally it occurs in ap-

proximately 1 out of 4 plants. One such ratio of 13 green to 3 yellow indicates that it is probably due to a single gene.

The  $y_8$  type is a chlorophyll-deficient type characterized by yellow-green leaves in the young plant. As the plant develops the leaves become more greenish and the newer leaves formed show the deficiency less and less until the plant cannot be distinguished from the normal green. There seems to be some reduction in vigor though very little. The  $y_8$  type has not been tested in crosses as yet and there are no segregating progenies available from which an idea of its inheritance can be gained.

### NEW LINKAGE RELATIONSHIPS

Pubescence color, gene pair  $Tt$ , is assumed to be in chromosome I. A cross between the Elton variety and a variegated leaf type ( $v_1$ ) showed evidence of linkage between pubescence color and cotyledon color, repulsion phase. The data are given in Table 2.

TABLE 2.—Data showing linkage between pubescence color and cotyledon color.

F <sub>2</sub> classes	Tawny pubescence		Gray pubescence		Total
	Yellow cotyledon	Green cotyledon	Yellow cotyledon	Green cotyledon	
Actual results. . . . .	99	11	51	1	162
Expected results (45:3:15:1) . . . . .	114	7.5	38	2.5	162
Expected results (13% crossing over)	112	10	40	0	162

The previously mentioned cross also segregated for green vs. yellow seed coat color. This character was formerly found by Woodworth (4)<sup>3</sup> to be linked to one of the duplicate cotyledon factors, arbitrarily designated  $d_1$ , with about 13% crossing over. The linkage relationship was again confirmed by the results of this cross (Table 3).

TABLE 3.—Data showing linkage between green vs. yellow seed coat color and yellow vs. green cotyledon color.

F <sub>2</sub> classes	Green seed coat		Yellow seed coat		Total
	Yellow cotyledon	Green cotyledon	Yellow cotyledon	Green cotyledon	
Actual results. . . . .	101	12	48	0	161
Expected results (45:3:15:1) . . . . .	113	7.5	38	2.5	161
Expected results (13% crossing over)	111	10	40	0	161

Pubescence color and coat color (green vs. yellow) showed random assortment as indicated in the segregation ratios given in Table 4.

Since therefore, genes  $t$  and  $g$  are independent and located on different chromosomes, and since  $g$  is arbitrarily assumed to be linked

<sup>3</sup>Figures in parenthesis refer to "Literature Cited", p. 129.

TABLE 4.—Data showing independence between pubescence color and coat color.

F <sub>2</sub> classes	TG	Tg	tG	tg	Total
Actual results . . . . .	87	29	27	18	161
Expected results (9:3:3:1) . . . . .	91	30	30	10	161

with  $d_1$ , then  $t$  may be considered to be linked with  $d_2$ . Hence, in the revised soybean chromosome map,  $d_2$  is added to chromosome I, and located 13 units from  $t$ . It has not yet been determined, however, whether  $d_2$  is just 7 units from  $e$ , as is indicated on the revised map, and since  $e$  stock has been lost, it will be impossible to determine this point.

Evidence for a fourth group of linked genes was obtained from three crosses which involved genes  $p_2$  (glabrousness) and  $de_2$  (defective seed coat). The data are given in Table 5.

TABLE 5.—Data showing linkage between glabrousness and defective seed coat (coupling phase).

Cross No.	F <sub>2</sub> classes				Crossing over
	P <sub>2</sub> De <sub>2</sub>	P <sub>2</sub> de <sub>2</sub>	p <sub>2</sub> De <sub>2</sub>	p <sub>2</sub> de <sub>2</sub>	
44 . . . . .	97	3	1	8	2.0 +
104 . . . . .	27	0	0	3	0.0
151 . . . . .	72	0	0	18	0.0
Total . . . . .	196	3	1	29	

These genes are, therefore, assumed to be located on chromosome IV about 2 units apart. This type of defective coat is different from that reported by Stewart and Wentz (2) as linked with pubescence color. It has a net-like appearance, occurs in combination with either tawny or gray pubescence, and on variously colored seed coats.

Formerly genes  $p_1$  and  $r_1$  were located on chromosome II, 12 units apart, and  $P_1$  18 units from  $M$ . However, from this information it could not be determined whether the gene order was  $p_1-r_1-m$  or  $r_1-p_1-m$ . Knowledge of the relationship between  $r_1$  and  $m$  was needed to settle this point. In a cross between F. P. I. 91073 and F. P. I. 84896, gene pairs  $r_1r_1^0$  (brown coat vs. reddish brown coat) and  $Mm$  (mottling vs. self-color) were involved in the coupling phase. The  $F_2$  ratios are given in Table 6.

TABLE 6.—Data showing linkage between gene pairs  $r_1r_1^0$  and  $Mm$ .

F <sub>2</sub> classes	Mr <sub>1</sub>	Mr <sub>1</sub> <sup>0</sup>	mr <sub>1</sub>	mr <sub>1</sub> <sup>0</sup>	Total
Actual results . . . . .	60	11	10	11	92
Expected ratio (no linkage) . . . . .	9	3	3	1	16
Expected results (no linkage) . . . . .	52	17	17	6	92
Expected results (30% crossing over)	57	12	12	11	92

Owen (1) made the observation that there should be linkage between these gene pairs, but his numbers were too small to indicate any. In certain cases where the crossing over percentage is as high as 30, the data might indicate independent inheritance.

In the light of these data, then, the gene order in chromosome II is established as  $r_1$ - $p_1$ - $m$  as indicated on the provisional map (Fig. 1).

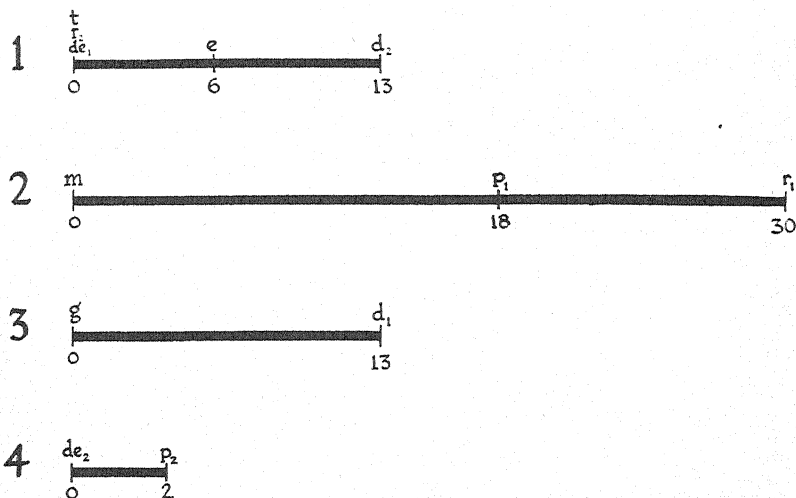


FIG. 1.—Provisional soybean chromosome map.

Other gene pairs have shown relationships in inheritance. Takahashi (3) reports a linkage between leaf shape and number of seeds per pod, with a cross-over percentage of about 10. This may constitute a fifth chromosome group. We have also observed this relationship but have not been able so far to determine the strength of linkage. Also, we have noted a tendency for  $f$  (fasciation) to be associated with late maturity. The evidence indicates that  $f$  may be located on chromosome I.

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A STUDY OF THE TIME OF PASTURING ALFALFA<sup>1</sup>H. C. RATHER AND A. B. DORRANCE<sup>2</sup>

IN previous studies of alfalfa used for pasture which the authors have made in Michigan,<sup>3</sup> grazing was discontinued by September 1 to give the plants opportunity to store root reserves before winter. On the basis of other work at this station indicating that the clipping of alfalfa during September was particularly injurious,<sup>4</sup> it was assumed that close grazing would likewise prove detrimental.

In 1936, a time-of-grazing experiment was started to gain additional information on the influence of fall grazing on the alfalfa and to determine the time in the spring when grazing could be started safely. The experiment was conducted on Bellefontaine sandy loam soil limed for the correction of acidity and seedings were made in 1935, at which time 250 pounds per acre of 0-8-24 fertilizer were applied. Hardigan alfalfa was seeded in oats and good stands were secured.

The grazing methods here reported were carried on in 1-acre paddocks, each time-of-grazing treatment being run in triplicate. The grazing practices followed were (a) pastured from April 30 to August 28; (b) pastured May 14 to August 28; and (c) pastured May 14 to October 16.

May, June, July, and early August were unusually dry, precipitation during this period being only 5.89 inches, about 50% of normal. From August 18 to October 16, 12.26 inches of rain fell at this station, about twice the normal. From July 7 to July 15, the maximum temperature each day exceeded 100° F, a record heat wave for this locality. In general, all paddocks were pastured off completely by August 28. New growth was stimulated by the late August and September rains. All alfalfa made an excellent recovery and that pastured throughout September and the first half of October furnished good grazing for eight spring lambs per acre, each of which made good gains during this period. The results are presented in Table 1.

It is not intended, at this early stage in the experiment, to draw definite conclusions concerning livestock returns from the different grazing treatments. This is particularly true in dealing with any comparison between grazing April 30 to August 28 and May 14 to August 28. For the present, these returns must be considered com-

<sup>1</sup>Contribution from the Section of Farm Crops, Michigan Agricultural Experiment Station, East Lansing, Mich., and the Division of Forage Crops and Diseases, U. S. Dept. of Agriculture. Journal Article No. 313 (new series) of the Michigan Agricultural Experiment Station. Received for publication November 23, 1937.

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Acknowledgements are due Professor G. A. Brown, Michigan Experiment Station, and C. M. McCrary, Superintendent W. K. Kellogg Farm, for selection and supervision of the sheep used on these pastures.

<sup>3</sup>RATHER, H. C., and DORRANCE, A. B. Pasturing alfalfa in Michigan. Jour. Amer. Soc. Agron., 27:57-65. 1935.

<sup>4</sup>SILKETT, VAL W., MEGEE, C. R., and RATHER, H. C. The effect of late summer and early fall cutting on crown bud formation and winter hardiness of alfalfa. Jour. Amer. Soc. Agron., 29:53-62. 1937.

TABLE 1.—*Grazing returns from alfalfa under different time-of-grazing treatments, W. K. Kellogg Farm of Michigan State College, 1936.\**

Grazing period	Treatment and grazing returns								
	Pastured Apr. 30-Aug. 28			Pastured May 14-Aug. 28			Pastured May 14-Oct. 16		
	Sheep- days pasture	Gains, lbs. per acre	Gains, lbs. per sheep- day	Sheep- days pasture	Gains, lbs. per acre	Gains, lbs. per sheep- day	Sheep- days pasture	Gains, lbs. per acre	Gains, lbs. per sheep- day
Apr. 30- May 14....	149	109.7	0.736	—	—	—	—	—	—
May 14- May 28....	88	61.9	0.703	236	219.9	0.932	215	162.0	0.753
May 28- June 25....	93	57.3	0.616	140	53.0	0.379	97	33.5	0.345
June 25- July 23....	112	33.0	0.295	150	23.0	0.153	154	59.7	0.388
July 23- Aug. 28....	131	8.6	0.066	75	-3.3	0.044	152	-11.6	0.076
Aug. 31- Oct. 16....	—	—	—	—	—	—	184	125.7	0.683
Total.....	573	270.5	—	601	292.6	—	802	369.3	—
Average gain in lbs. per sheep-day...			0.472			0.486			0.460

\*The figures represent average acre returns from three 1-acre paddocks used for each treatment. One of the paddocks in the April 30 to August 28 treatment and one in the May 14 to October 16 treatment were on land previously infested with downy brome grass (*Bromus tectorum*) and this weed was present in appreciable quantities in these two paddocks. Grazing returns from them were comparable to those from the non-infested paddocks and are included in this report, but the presence of the downy brome grass may influence the alfalfa adversely in the future.

parable. Neither was there any noticeable difference in the final behavior of the alfalfa under these two treatments. In both cases, excellent fall recovery was made and the alfalfa survived the winter in fine condition and made a vigorous growth in the season of 1937.

The purpose of the present report is to point out that the three paddocks pastured from May 14 to October 16 were very severely injured by the fall grazing. In treatment, this series differed from the one pastured May 14 to August 28 only by the grazing of eight lambs per acre from August 31 to October 16. The lambs averaged 61½ pounds each on August 31 and 77.3 pounds each on October 16. In calculating sheep-days pasture, two lambs were considered the equivalent of one mature sheep.

During the six weeks in September and October that lambs were on this pasture, they kept the alfalfa short and consequently, during this critical fall period, the alfalfa had no opportunity to store an adequate supply of reserve food.

In late October, and again in late November, root samples of alfalfa were dug from the three grazing treatments and root weight, percentage dry matter, and laboratory winterhardiness determinations were made. Winterhardiness was measured by means of electri-



cal conductivity as described by Dexter, *et al.*<sup>5</sup> The results of these determinations are presented in Tables 2 and 3.

TABLE 2.—*Comparative influence of time-of-grazing alfalfa on root and crown bud development in the fall.\**

Grazing period	Green weight of 100 roots (upper 5 inches), grams	Dry Matter %	Dry weight of 100 roots, grams	No. crown buds on 100 roots	Green weight of crown buds, grams	Dry weight of crown buds, grams
Alfalfa Sampled Oct. 30, 1936						
Apr. 30 to Aug. 28....	344	39.80	137	1002	71.10	7.30
May 14 to Aug. 28....	353	38.44	136	1068	79.06	8.01
May 14 to Oct. 16....	209	32.28	67	172	7.43	1.45
Alfalfa Sampled Nov. 28, 1936						
Apr. 30 to Aug. 28....	312	33.60	105	1624	85.20	16.28
May 14 to Aug. 28....	298	34.74	104	1704	113.66	30.56
May 14 to Oct. 16....	190	31.35	60	900	31.02	3.42

\*Determinations reported in Tables 2 and 3 were made by S. T. Dexter, Farm Crops Section, Michigan Experiment Station.

TABLE 3.—*Comparative influence of time-of-grazing alfalfa on winterhardiness of the plants as indicated by electrical conductivity determinations.*

Grazing period	Specific conductivity* $\times 10^7$	
	Sampled Oct. 30	Sampled Nov. 28
April 30 to August 28.....	1,976	1,882
May 14 to August 28.....	1,749	2,268
May 14 to October 16.....	1,933	2,833

\*All conductivity figures represent the average of three determinations.

The data in Table 2 indicate an adverse response of the alfalfa plants to close fall grazing. The roots of the alfalfa not pastured in the fall were not only heavier but higher in percentage dry matter. The opportunity for fall storage of root reserves was associated with the development of larger, more vigorous, and a great many more crown buds.

As indicated by the electrical conductivity determinations, hardening of the alfalfa was not far advanced when the first samples were dug October 30, but a month later the alfalfa from the two series not grazed in the fall was in a materially more hardened condition than that pastured during September and October.

<sup>5</sup>DEXTER, S. T., TOTTINGHAM, W. E., and GRABER, L. F. Investigation of hardiness of plants by measure of electrical conductivity. *Plant Phys.*, 7:63-78. 1932.

The final indication of the adverse influence of the fall grazing was the way in which the alfalfa survived the open winter of 1936-37. General observations throughout this section of Michigan indicated winterkilling of both wheat and alfalfa to be somewhat more prevalent than usual. However, no winterkilling of alfalfa was apparent in any of the paddocks in which grazing was discontinued August 28, regardless of treatment earlier in the season.

The three paddocks grazed August 31 to October 16 presented a vastly different picture. The well-drained sandy loam soil on which these trials were conducted is not one on which heaving is usually a serious problem. Yet, when these paddocks were observed in late March, more than 90% of the alfalfa plants had been so weakened by freezing injury that they were heaved 2 to 4 inches out of the ground. In two of the three paddocks, most of these heaved plants were dead and when growth started in late April, only a very small percentage of the plants were alive. The plants which survived tended to be in patches that were possibly grazed less severely in the fall than the balance of the field. The alfalfa stand in these two paddocks could properly be described as ruined for all further use either for grazing or for hay.

The third paddock was somewhat lower and possibly in a little better state of fertility, and, although heaving of the plants was almost universal, the mortality was not so great. A fair stand of alfalfa, slower to start and lacking in vigor still remained the following spring. This was the only paddock of the three to have enough alfalfa to warrant continuation of grazing in the season of 1937.

Although it is possible that, during a more favorable winter, the actual killing of fall-grazed alfalfa might not be so general as it was in the trials here reported, the alfalfa on which grazing was discontinued August 28 came through the winter in excellent condition and that pastured closely in September and October was injured so severely that it appears worthwhile to report this phase of the experiment at this time.

#### SUMMARY

Alfalfa was pastured April 30 to August 28, May 14 to August 28, and May 14 to October 16, each grazing treatment being carried on in three 1-acre paddocks.

Grazing returns as indicated by sheep-days pasture and gains per acre were comparable for the three treatments up to August 28, with additional returns secured from that pastured May 14 to October 16 being due entirely to fall grazing.

The alfalfa pastured in the fall had less dry matter per 100 roots and had developed fewer and much less vigorous crown buds when sampled October 30 and November 28.

Electrical conductivity determinations with the alfalfa roots indicated that the alfalfa on which grazing was discontinued August 28 had hardened off much better by November 28 than that pastured in the fall regardless of previous treatment.

Root starvation caused by fall grazing in September and October and heaving of the dead plants during winter and spring was almost

universal in the fall-pastured alfalfa, and in two of the three paddocks the stands left in the spring of 1937 were of little use either as hay or pasture.

The alfalfa not pastured in September and October showed no indications of winter injury, no heaving was apparent, and excellent stands of vigorous alfalfa were available for continuation of pasture in 1937.

## INOCULATION OF SESBAN<sup>1</sup>

C. F. BRISCOE AND W. B. ANDREWS<sup>2</sup>

SESBAN has come into agricultural importance as a summer green manuring crop in recent years,<sup>3</sup> but it has no value as a forage crop for stock do not like it. There are two species of sesban given in Small's "Manual of the Southern Flora" and both are native to North America.<sup>4</sup> *Sesban emerus* Aubl. occurs in Alabama, Georgia, Florida, New Mexico, the West Indies, and Central America; while *Sesban exaltata* (Raf.) Rydb. occurs on the low grounds, stream banks, and fields of the coastal plains and adjacent provinces of Mississippi, Louisiana, Arkansas, Oklahoma, Texas, and Missouri.

There are no published data on the inoculation of sesban so far as the writers know; however, McKee puts it in the cowpea inoculation group. The writers have observed that sesban growing upon upland soils which were naturally inoculated for cowpeas failed to produce efficient nodules even though a few nodules occurred upon the roots. The work reported in this paper was therefore undertaken.

### EXPERIMENTAL PROCEDURE

Inoculation tests with *Sesban exaltata* were conducted both in the greenhouse and in the field. The greenhouse tests were made in 4-inch sterile flower pots using sterilized sand and seed. Both negative and positive checks were used in each series of tests. The negative checks were made without inoculation, while the positive checks were made using sesban, cowpea, and garden bean seed inoculated with a culture suited to the particular plant. The results were not accepted unless the negative checks were free from nodules and the positive checks were well inoculated.

Nine strains of Rhizobia were isolated from sesban for these tests. Five strains were isolated from sesban growing wild on the banks of a stream near State College, three strains were obtained from sesban which had been planted on one area on the experiment station farm, and one strain was obtained from sesban which had been growing for several years on the experiment station farm at West Point, Mississippi. The sesban grown on the experiment station farms had not received artificial inoculation. In addition stock cultures of garden bean, cowpea, and other members of the cowpea cross-inoculation group—mungbean, hyacinth bean, peanut, lima bean, pigeon pea and lespedeza—were used.

The greenhouse tests were used for preliminary trials only, after which tests were conducted in the field to determine the efficiency of a more limited number of strains. The field tests were conducted on Oktibbeha fine sandy loam of pH 4.3. The sesban was planted in plats 1/400 acre in size. The plats consisted of a single row, 3½ feet wide and 31.1 feet long. Lime (dolomite) was applied in the drill at the rate of 400 pounds per acre; 250 pounds of 0-8-4 fertilizer were also applied in the drill with the seed.

<sup>1</sup>Contribution from the Department of Agronomy, Mississippi Agricultural Experiment Station, State College, Miss. Received for publication November 26, 1937.

<sup>2</sup>Bacteriologist and Associate Agronomist, respectively.

<sup>3</sup>McKee, Roland. Summer crops for green manuring and soil improvement. U. S. D. A. Farmers' Bulletin 1750. 1935.

<sup>4</sup>Small, J. K. Manual of the Southern Flora. 1935. (Pages 702-703.)

The cowpea, peanut, and lima bean cultures used in the field experiments were combinations of two efficient strains of the particular group of *Rhizobia*. The pigeon pea, hyacinth bean, mungbean, peanut, lima bean, and sesban cultures were isolated by the senior author.

### RESULTS AND DISCUSSION

The greenhouse data are qualitative only, while the field data are both qualitative and quantitative.

#### GREENHOUSE DATA

The data obtained in the greenhouse upon the ability of strains of cowpea, garden bean, and sesban *Rhizobia* to inoculate sesban are reported in Table 1.

TABLE 1.—*The ability of strains of cowpea, garden bean, and sesban Rhizobia to produce nodules on sesban in the greenhouse.*

Culture used	Source of culture	Nodules produced on		
		Cowpea	Sesban	Garden Bean
603, garden bean.....	U. S. Dept. Agr. ....	None	Abundant	Abundant
605, garden bean.....	Univ. Wisc.....	None	Good	Abundant
606, sesban..	Miss. State.....	None	Abundant	Good
607, sesban..	Miss. State.....	None	Abundant	Fair
608, sesban..	Miss. State.....	None	Abundant	Abundant
609, sesban..	Miss. State.....	None	Abundant	Fair
610-614, sesban.....	Miss. State.....	None	Abundant	Few
11, cowpea..	Univ. Mo.....	Abundant	Few	None
15, cowpea..	Stimugerm.....	Abundant	Few	None
20, cowpea..	Univ. Ill.....	Abundant	None	Few
24, cowpea..	Univ. Wisc.....	Abundant	Few	None
56, cowpea..	Univ. Fla. beggerweed	Good	Few	Few
32, cowpea..	Miss. State mungbean	Abundant	Few	Very few
34, cowpea..	Miss. State hyacinth bean.....	Abundant	Few	None
38, cowpea..	Miss. State peanut....	Abundant	Good	Very few
42, cowpea..	Miss. State lima bean	Abundant	Few	Abundant(?)
50, cowpea..	Miss. State pigeon pea	Abundant	Few	Fair
55, cowpea..	Univ. Fla. lespedeza..	Abundant	Few	Few

The cowpea strains of *Rhizobia* produced nodules abundantly on cowpeas in all cases except one which is listed as good. They produced a few nodules on the sesban plant in 10 cases out of 11 and failed to produce any nodules in one case. The cowpea strains usually produce none to a few nodules on garden beans except in one case which was recorded as abundant. The latter data are probably in error.

The two garden bean strains of *Rhizobia* produced no nodules on cowpeas, good and abundant nodules on sesban, and abundant nodules on garden beans. Evidently the garden bean culture is able to produce nodules on sesban.

The *Rhizobia* isolated from sesban produced no nodules on cowpeas. As was noted above, sesban has been considered to be inocu-

lated by cowpea *Rhizobia*. The sesban cultures produced nodules abundantly on the sesban plants. In every case the garden bean inoculated with sesban culture produced nodules, varying from a few to abundant.

Summarizing the greenhouse work, it is seen that the cowpea cultures produce abundant nodules on cowpeas and usually a few nodules on sesban and garden beans. The garden bean cultures produce nodules on both sesban and garden beans but not on the cowpea, while the cultures isolated from sesban produce abundant nodules on sesban, a few on garden beans, and none on cowpeas.

## FIELD DATA

The effect of strains of garden bean, cowpea, and sesban *Rhizobia* upon the yield and nitrogen content of sesban in the field is reported in Table 2.

TABLE 2.—*The effect of strains of cowpea, garden bean, and sesban Rhizobia upon the yield and nitrogen content of sesban.*

Culture	Source	Increase or decrease in yield per acre of air-dry sesban due to inoculation, as compared with check, pounds per acre	Percentage of nitrogen in air-dry sesban
603, garden bean.	U. S. Dept. Agr. ....	-95 ± 160*	1.01 ± 0.086
605, garden bean.	Univ. Wis. ....	-2 ± 117	1.10 ± 0.012
608, sesban. ....	Miss. State. ....	642 ± 120	1.70 ± 0.069
610, sesban. ....	Miss. State. ....	822 ± 143	1.80 ± 0.076
613, sesban. ....	Miss. State. ....	800 ± 178	1.71 ± 0.096
20-24, cowpea. ....	Miss. State. ....	190 ± 97	1.11 ± 0.094
38-39, cowpea. ....	Miss. State peanut. . .	-90 ± 126	0.99 ± 0.049
42-43, cowpea. ....	Miss. State lima bean	22 ± 157	1.07 ± 0.049
Check. ....		2,257	0.99 ± 0.045

\*Standard error.

The garden bean and the cowpea cultures did not increase the yield of sesban significantly in any case. The check yield was 2,257 pounds of air-dry sesban per acre. Cowpea culture produced  $190 \pm 97$  pounds per acre more than the check. This increase is hardly significant. The three sesban cultures produced increases of  $642 \pm 120$ ,  $822 \pm 143$ , and  $800 \pm 178$  pounds standard error of air-dry sesban per acre. These increases are highly significant, but differences between them are not significant.

The sesban culture increased the percentage of nitrogen from  $0.99 \pm 0.045$  to  $1.70 \pm 0.069$ ,  $1.80 \pm 0.076$ , and  $1.71 \pm 0.096$ . These differences are highly significant, but, as in the case of yield, differences between them are not significant. The sesban inoculated with garden bean 605 had a nitrogen content of  $1.10 \pm 0.012$  which, in comparison with the check, is barely significant. The other garden bean culture and the cowpea cultures did not increase the nitrogen content of sesban significantly.

## SUMMARY

The ability of strains of garden bean, cowpea, and sesban Rhizobia to inoculate sesban was tested qualitatively in the greenhouse, using both negative and positive checks, and both qualitatively and quantitatively in the field with the following results:

1. Garden bean Rhizobia produced good to abundant nodulation on sesban.
2. Cowpea Rhizobia produced a few nodules on sesban.
3. Rhizobia isolated from sesban produced abundant and efficient nodulation on sesban.
4. The yields of sesban inoculated with sesban cultures were increased about 35%.
5. The percentages of nitrogen in sesban inoculated with sesban cultures were increased about 0.75%.
6. Strains of cowpea and garden bean Rhizobia did not increase the yield nor the nitrogen content of sesban significantly.

## CONCLUSION

Inoculation of sesban with an efficient sesban culture will, in most cases, significantly improve sesban as a summer green manure. Sesban belongs to an inoculation group which is different from cowpea and garden bean. Until further work is carried out, sesban should be considered to be in the "Sesban Inoculation Group".

## THE AMOUNT OF DUST IN THE AIR AT PLANT HEIGHT DURING WIND STORMS AT GOODWELL, OKLAHOMA, IN 1936-1937<sup>1</sup>

WRIGHT H. LANGHAM, RICHARD L. FOSTER, AND  
HARLEY A. DANIEL<sup>2</sup>

DUST storms are not new (6, 7),<sup>3</sup> but they have been more severe in the southern high plains and the adjacent territory since 1933 than in previous years. Few attempts have been made to measure their intensity and little information is available regarding the amount of soil which is present in the atmosphere. The continuation of dust storms of unusual severity during the past four years has developed a national interest in the problem of wind erosion and soil conservation. The agricultural significance of dust storms has been studied by various investigators and a review of recent literature was made by Daniel, Langham, and Foster (2). In this report some of the problems created by drifting soils, such as plant nutrient losses and changes in physical properties of soils, effect on machinery, railroads, highways, and on living conditions were described.

Several different methods have been used to collect dust from the air such as shallow pans containing water and tall containers with vertical walls which act as settling basins. In areas of high wind velocities only the heavier particles will collect in these types of containers. After the wind stops blowing, the dust in the air will settle, but it does not represent the movement of dust in any area. In order to estimate the amount of soil in the atmosphere under different conditions, the apparatus described below was introduced.

### EXPERIMENTAL PROCEDURE

An impinger tube, as recommended by the Public Health Service (5) for measuring industrial dusts, was chosen as a means of removing the dust from the air. It was necessary to enlarge and modify the entire set-up since large quantities of dust traveling at a high velocity presented a decidedly different problem from factory and mine dusts which are collected from a quiet atmosphere.

The apparatus consists essentially of suction to draw the dust through the sampling device, a meter for measuring the air, and an impinger or sampling tube. An Electrolux vacuum cleaner was used as a source of suction and the air was measured with a 10-B metric gas meter. The impinger flask consisted of a 2½ by 18-inch hydrometer jar closed with a two-hole rubber stopper. One hole carried an outlet tube of 14-mm glass tubing bent to a right angle. The other hole carried the impinger tube. It was made by drawing a piece of 14-mm glass tubing down to a tip with a 5-mm orifice, and the tube was adjusted in the stopper so that the

<sup>1</sup>Contribution from the Oklahoma Agricultural Experiment Station, Stillwater, Okla. The work was conducted at the Panhandle Agricultural Experiment Station, Goodwell, Okla. Received for publication November 29, 1937.

<sup>2</sup>The authors wish to express their appreciation to Electrolux, Inc., and to the Panhandle Power and Light Company for use of vacuum cleaner and 10-B metric gas meter.

<sup>3</sup>Figures in parenthesis refer to "Literature Cited", p. 144.



narrow opening was about 1 cm from the bottom of the flask. The upper end of the tube was bent at a right angle making it parallel to the wind.

The three pieces of apparatus were arranged on a portable bench, as shown in Fig. 1, with the meter between the impinger flask and the vacuum cleaner. The suction end of the vacuum cleaner was connected to the outlet side of the meter and the inlet side was connected to the outlet of the impinger flask. All connections

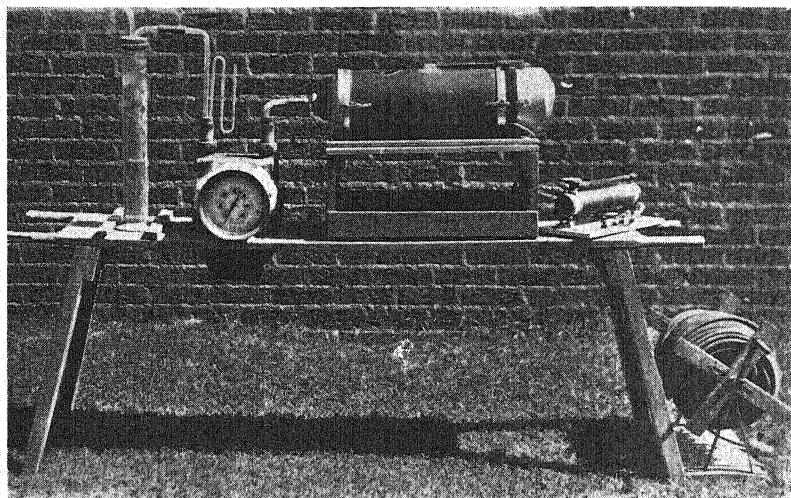


FIG. 1.—The machine used for collecting the dust.

were made with 14-mm glass tubing. The inlet and outlet to the meter were fitted with mercury manometers so that the decrease in pressure in the meter could be measured. The manometer readings were used to correct the meter reading to volume of air under atmospheric conditions.

The impinger flask was thoroughly cleaned and filled with distilled water to a depth of 4 or 5 inches. The apparatus was carried into the field of the Panhandle Experiment Station, 400 feet from buildings and other obstructing objects. Electricity was supplied by a long extension cord and the speed of the electric motor in the vacuum cleaner was reduced with a rheostat. The intake tube was placed at a height of 30 inches from the ground and turned directly into the wind. The time, meter reading, wind direction, wind velocity, manometer readings, and approximate visibility were taken during the test. The dust which was drawn in with the air was trapped in the water in the impinger flask. The flask was changed at convenient intervals, depending on the severity of the storm.

The quantity of dust was determined by evaporating the water and weighing the residue. The amount of dust in milligrams per cubic foot of air was determined by dividing the weight of dust in grams by the corrected volume of air passing through the impinger flask.

## RESULTS

### AMOUNT OF DUST IN AIR DURING WIND STORMS

The amount of dust carried by the wind in 29 dust storms in 1936 and 1937 was measured and the data recorded in Table 1. During this

Date of storm	No. of samples	Period of measurements per storm			Wind velocities, miles per hour	General wind direction	Approximate visibility, yards	Milligrams of dust per cubic foot of air*
		Clock start	Hours end	Total minutes sampled				
1936								
Apr. 4.....	3	2:24 p.m.	3:52 p.m.	46	23.0±4.0	W-SW	70±24	57±10
5.....	2	11:44 a.m.	3:22 p.m.	60	26.0±0.0	N-NE	80±0	40±5
8.....	2	11:16 a.m.	3:22 p.m.	90	24.5±1.5	S-SW	667±178	7±3
9.....	2	9:47 a.m.	11:08 a.m.	45	32.0±0.0	N-NE	112±81	62±17
20.....	3	6:23 p.m.	7:19 p.m.	37	30.0±0.0	N	28±18	102±48
23.....	5	9:12 a.m.	2:52 p.m.	311	24.4±17.2	S-SW	630±274	9±4
29.....	2	5:22 p.m.	6:45 p.m.	78	20.5±4.5	SW	550±160	6±2
May 5.....	6	3:00 p.m.	7:41 p.m.	143	23.3±2.0	S-SW-SE	238±169	32±13
8.....	2	3:55 p.m.	5:15 p.m.	70	22.5±2.5	NW	38±24	67±22
1937								
Feb. 7.....	1	11:00 a.m.	7:20 p.m.	500	30.0±0.0	SW	105±95	55±0
11.....	1	2:40 p.m.	6:25 p.m.	225	23.0±0.0	S-SW	400±00	6±0
14.....	3	8:30 a.m.	3:03 p.m.	405	24.3±3.4	S-SW	150±14	38±24
15.....	2	10:40 a.m.	5:30 p.m.	380	19.0±1.0	NW-N	285±80	5±2
16.....	6	10:00 a.m.	5:40 p.m.	432	25.5±2.2	S-SW	333±386	48±40
17.....	3	8:50 a.m.	3:05 p.m.	370	21.5±2.5	N-NE	126±158	8±6
18.....	2	12:55 p.m.	5:40 p.m.	133	32.0±0.0	SW	146±147	50±44
Mar. 3.....	5	9:55 a.m.	7:21 p.m.	617	20.7±7.8	NW-N	181±56	8±2
9.....	3	9:25 a.m.	1:20 p.m.	235	22.5±2.7	SW-W	472±343	19±12
17†.....	1	12:55 p.m.	2:40 p.m.	105	17.1±0.0	N-NE	440±00	5±0
19.....	6	12:30 p.m.	6:37 p.m.	363	21.4±1.2	NW-N	88±62	39±14
23.....	7	9:30 a.m.	10:30 p.m.	822	30.0±1.0	SW	21±23	115±32
24.....	5	10:04 a.m.	8:20 p.m.	676	19.8±2.8	NW-N	90±100	43±25
Apr. 2.....	3	9:19 a.m.	5:55 p.m.	501	18.4±3.9	SW	540±272	10±5
3.....	3	8:53 a.m.	2:05 p.m.	300	14.0±1.3	N	465±107	6±4
6.....	4	1:34 p.m.	6:43 p.m.	300	24.4±1.5	SW	155±109	29±18
16.....	4	9:48 a.m.	5:58 p.m.	480	20.7±1.3	SW	251±108	12±7
22.....	4	1:32 p.m.	6:52 p.m.	300	21.1±2.8	SW	147±92	30±14
23.....	4	8:30 a.m.	4:47 p.m.	335	19.2±4.2	NW-N	319±273	33±20
May 3.....	5	8:40 a.m.	7:38 p.m.	656	23.4±1.3	NW	426±226	13±7
Average.....	3.4			311	23.2±2.5		260±123	33±14

\*Measurements were all taken about 30 inches above the surface of the ground.

†Water still standing in field from recent rains.

period 27 determinations were made in 9 major storms occurring from April 4 to May 8, 1936, and 74 in 20 severe storms from February 7 to May 3, 1937. Many dust storms began and ended during the night, and since the apparatus could not be kept in continuous operation or set up in time to measure the beginning of each blow, the amount of dust per cubic foot of air for a complete storm was not always obtained. When such conditions occurred, attempts were made to take at least one sample at a time when the storm appeared to reach a maximum intensity. Due to numerous complications, only two dust storms in 1936 (April 23 and May 5) were measured throughout their duration. Complete results were recorded from several storms in 1937.

The average of all readings taken in a particular storm was calculated and considered representative of the amount of dust in the air during a period of high wind. Owing to variable nature of the wind, considerable variation occurred in the results obtained during a continuous dusty period and also between different storms. The average amount of dust collected from the air during all storms was  $33 \pm 14$  milligrams per cubic foot. In these experiments the dust was collected about 30 inches above the ground and the data do not show the quantity of soil drifting away from the high plains. According to Udden, cited by Twenhofel (7), "on the average, 850,000,000 tons of dust are carried in the Mississippi Valley 1,440 miles each year". He also states that the dust carried in the atmosphere over the Mississippi Valley is one thousand times as great as the quantity of sediment transported by the Mississippi River system.

Since measurements were not taken throughout the dusty season in 1936, a more reliable comparison of severity of storms may be obtained from the data in Table 2. The years of 1933, 1934, and 1935 contained 70, 22, and 53 days, respectively, that had sufficient dust to lower visibility in comparison with 73 for 1936, and 117 from January 1 to August 1, 1937. Although visibility data in Table 1 were determined from observations, they do give a general idea of vision

TABLE 2.—*The number of days containing sufficient dust to lower visibility at Goodwell, Oklahoma, from January 1, 1933, to August 1, 1937.*

Month	Year					Average
	1933	1934	1935	1936	1937	
Jan.....	4	2	2	0	9	3.4
Feb.....	4	0	7	9	14	6.8
Mar.....	14	6	11	18	18	13.4
Apr.....	17	6	20	16	21	16.0
May.....	12	2	6	14	23	11.4
June.....	7	2	1	1	17	5.6
July.....	3	0	1	2	15	4.2
Aug.....	3	1	1	1	—	1.5
Sept.....	3	0	0	0	—	0.8
Oct.....	0	1	2	1	—	1.0
Nov.....	2	2	1	7	—	2.4
Dec.....	1	0	1	4	—	1.5
Total.....	70	22	53	73	117	68.0

during some of the storms at Goodwell, Oklahoma. Visibility was reduced to one-half mile or less in 72 storms that occurred in 1937. In 23 of these particular storms vision was 150 feet or less. Average wind velocity is highest during March, April, and May (4), and the greatest number of dusty days occurred during these months. With the exception of this year, there have been only three months of severe dust each season. In 1937 the soil continued to blow from January 1 to August 1 which was the last date of the observations included in this report.

Although dust storms may occur from almost any direction, the prevailing wind is from the southwest (4) in the Panhandle of Oklahoma. The average wind velocity (3) from 1925 to 1934, inclusive, was 7.9 miles per hour, while that reported during these storms averaged  $23.2 \pm 2.5$  miles per hour. The amount of dust in the air appears to be proportional to the wind velocity during a single storm; but, in different windy periods, there was probably no relation. This information substantiates conclusions drawn from general observations that wind turbulence is also an important factor in soil movement in this locality.

Storms in the past have varied in length from a few minutes to several hours and occasionally four or five have occurred in succession. They usually stop for a few hours in the afternoon or night and begin again from the opposite direction. Observations indicate that the duration of the average dust storm was about 10 hours dur-



FIG. 2.—The great black rolling dust storm that passed over Goodwell, Okla., May 21, 1937.

ing the dusty season. These storms have been of two types, the typical hard blows, and the great black blizzards (1) which apparently resulted from a well-developed polar front. The former type usually starts in the morning from the south or southwest continuing as the wind changes to the northwest or north until late afternoon or into the night. The black rolling type, Fig. 2, sweeps the plains at high velocities and produce an interval of total darkness followed by almost zero visibility for a considerable period. Only four of these storms have occurred in recent years. The first of known record was in June, 1922, the next was on April 14, 1935. Two of these storms occurred in 1937, the first on May 21 and the second on June 4.

#### SUMMARY

Measurements were made with an impinger tube to determine the amount of dust per cubic foot of air at various times during 29 dust storms of 1936 and 1937 occurring at Goodwell, Oklahoma. The average amount of dust collected in all storms was  $33 \pm 14$  milligrams per cubic foot of air. The average wind velocity during these storms was  $23.2 \pm 2.5$  miles per hour.

A record of the number of dusty days occurring at Goodwell, Oklahoma, from January 1, 1933, to August 1, 1937, shows that there were 70 dusty days in 1933, 22 in 1934, 53 in 1935, 73 in 1936, and 117 from January 1 to August 1, 1937.

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## COOPERATIVE PRODUCTION OF FOUNDATION STOCKS FOR CERTIFIED CORN HYBRIDS IN OHIO<sup>1</sup>

R. D. LEWIS AND G. H. STRINGFIELD<sup>2</sup>

A PLANNED program for the production of seed of adapted corn hybrids has been developed in Ohio to the point where in 1937, 260 growers produced commercial supplies of seed and a group of 320 apprentices were gaining experience with  $\frac{1}{8}$  or  $\frac{1}{4}$  acre crossing plats. By 1937 seed production had been initiated in each of the 88 counties. This cooperative research-extension production program is designed to make available reliable seed of adapted hybrids at a price consistent with the best interests of producers and users.

In developing a trained personnel for the production of hybrids, the Ohio program has given similar opportunities to small and large producers, these opportunities being based on interest, abilities, and nature of services rendered. Most of the producers in Ohio have crossing plats of relatively small acreages. In 1937, 68% of the commercial growers of certified hybrids in Ohio had crossing plats of 10 or fewer acres, 23% had crossing plats ranging from 11 to 50 acres, 5% had crossing plats of 51 to 100 acres, and only 4% of the producers had over 100 acres in crossing plats.

Inbred lines developed in Ohio were released to qualified growers for the first time in 1937. From 1933 to 1937, the Experiment Station, in cooperation with the Extension Service, the Bureau of Plant Industry, and two trained growers, accepted the responsibility for the production and distribution of foundation seed stocks of single crosses. This was a proper function and responsibility of the Experiment Station during the initial period of rapid development and change, for it assured effective use of materials created by research, gave time for the development of trained personnel, assured seed stocks to small as well as large producers, and made possible the correlation of production, distribution, and use of foundation seed stocks.

But in 1936 it became evident that the Experiment Station could not provide sufficient personnel nor physical equipment to produce and distribute the great volume of seed stocks that would be required in 1938. Also, the required activities of the research and extension staffs in seed stock activities were diverting time, energies, and thoughts from the fundamental research and educational programs. To build up reserve supplies of seed stocks, financing would be required. Research and extension leaders in the program, together with

<sup>1</sup>Contribution from the Ohio State University, the Ohio Agricultural Experiment Station, and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, cooperating. Also presented at the annual meeting of the Society held in Chicago, Ill., December 1, 1937. Received for publication December 9, 1937.

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a considerable group of producers who were giving thought to the future, concluded early in 1937 that the time had come for seed producers to take a more active part in making the results of research and extension efforts available to themselves, that they must begin to bear more of the costs and do more of the planning in order to be in a position to continue as producers and to assure themselves of having seed stocks available for producing the best new hybrids developed by public research institutions.

A committee of seven was elected by the growers at the Corn Hybrid School in January of 1937 to deliberate on problems and suggest actions that might aid the Ohio program for production and use of adapted hybrids. Recognizing at once the need for a cooperative program of attack on seed stocks problems, this committee, working with an advisory group from the Experiment Station and Extension Service, rapidly developed an outline of the form, functions, and activities of a cooperative seed stocks organization.

On February 18, 1937, the trustees formed a corporation, not for profit, and designated it the "Ohio Hybrid Seed Corn Producers". The main features of the set-up of the organization and its activities and relationships are detailed in Fig. 1.

Membership in the organization is open to persons, partnerships, or corporations who have been accepted as apprentice growers in the cooperative research-extension hybrid corn project of the Experiment Station, the Extension Service, and U. S. Bureau of Plant Industry, and those who have produced or are producing seed of corn hybrids under inspection and certification through the Ohio Seed Improvement Association. The membership entrance fee is \$5.00. The organization is governed by a Board of Trustees of seven members, each serving three years, two or three elected annually. An executive committee of three trustees conducts most of the current business. The Advisory Board is created by the Board of Trustees and must include two representatives from the Agronomy Department of the Experiment Station, one from the Extension Service, and the President of the Ohio Seed Improvement Association.

Late in February 1937 a statement, prepared and signed by the principals in the research-extension program of the Experiment Station, the Extension Service, and the Bureau of Plant Industry, was sent to all growers participating in the cooperative hybrid corn projects. This statement analyzed present and future problems and possible solutions in the production and distribution of foundation seed stocks in Ohio. Significant approval of the formation of the Ohio Hybrid Seed Corn Producers was combined with the announcements (1) that existing contracts and reserve seed stocks of the Experiment Station for production of released inbred lines and single crosses were offered for the use of the organization; (2) that the Experiment Station would no longer supply commercial producers of seed of corn hybrids with single crosses involving released inbred lines; and finally (3) that members of the research-extension staff would act as advisors in developing cooperative forward-looking seed stock programs.

The trustees followed the above statement with a formal announcement of the organization and a tentative outline of plans for 1937.

Membership applications and fees were solicited. To finance activities during 1937, an advance or reservation payment of \$2.00 per acre on the number of acres of double crossing plats estimated for production in 1938 was asked from each member.

The response from prospective members was so prompt and enthusiastic that in early March the trustees appointed a competent full-time manager, and authorized the 1937 production program for seed stocks as developed by the manager and the advisory board.

On November 10, 1937, the membership had reached 377, and these members had reserved, by a \$2.00 per acre advance payment, foundation single crosses for planting 7,100 acres of double crossing plats in 1938. It is estimated that the organization has from its 1937 operations sufficient seed of required single crosses for planting at least 13,000 acres of double crossing plats.

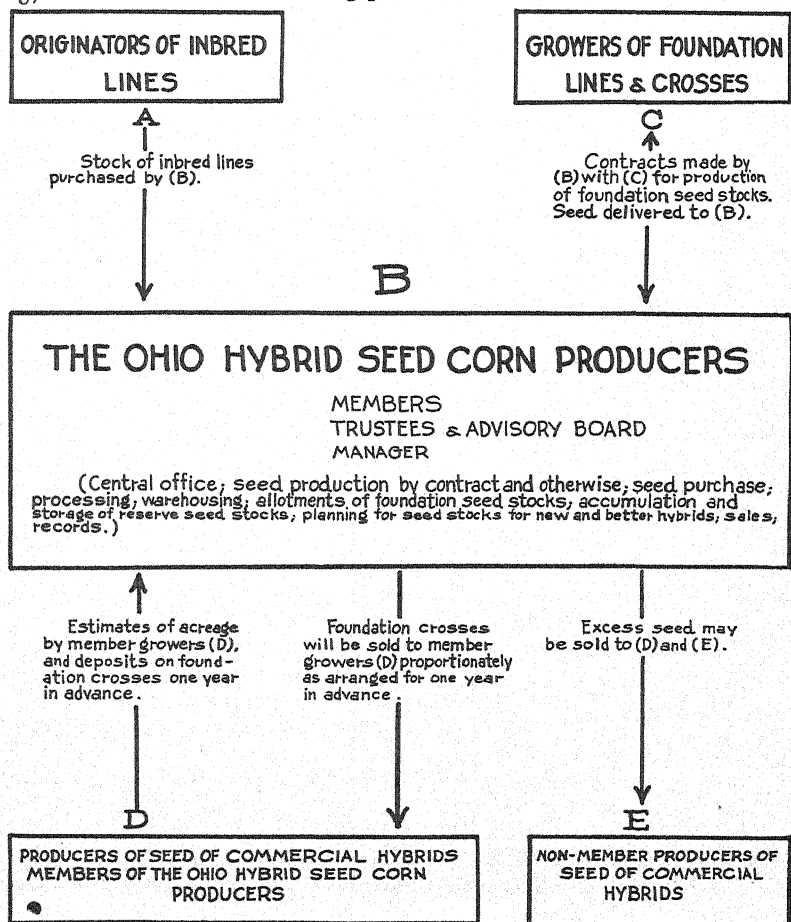


FIG. 1.—Diagram showing the seed stock activities of the Ohio Hybrid Seed Corn Producers, incorporated February 18, 1937.



Foundation seed stocks of single crosses and inbred lines were produced under contracts with 42 members in 25 different counties, with a total of 65 different plats and 198 acres. To distribute production risks each single cross was produced in from two to five crossing plats. Even in 1937 this proved desirable. The seed used in planting each of these plats came directly from releases by the Experiment Station or from certified seed stocks produced in 1936. Also, the Experiment Station produced for the organization seed stocks of a few lines and single crosses that are to be released in 1938. The organization also contracted with other seed stock producing agencies for 35 million viable seeds of single crosses to be used in producing certain hybrids developed out of the state and now eligible for certification in Ohio. Adequate reserve supplies of hand-pollinated seed of 20 inbred lines were also produced direct from originator's foundation seed stocks for the Ohio Hybrid Seed Corn Producers.

Foundation seed stocks of the following five classes were thus produced for and by the members of the cooperative seed stocks organization in 1937: (1) Inbred lines, hand-pollinated; (2) inbred lines, isolated plat increases; (3) inbred lines, from male rows of single crossing plats, eligible only for use as "female" hereafter; (4) First generation single crosses; and (5) advanced generation of single crosses, advanced in isolated plats from  $F_1$  seed, the only type of advance generation seed eligible for use in producing certified hybrids in Ohio in 1938.

All plats were inspected for certification through the Ohio Seed Improvement Association and all the seed is being inspected during processing and preparation for distribution. A contract with a grower of foundation seed provides that for seed rejected through his failure to meet the requirements for certification, only a nominal acre rate is paid him, but if the seed meets all conditions of the contract and certification requirements, the grower receives a sufficient sum per acre to encourage the greatest of care in producing and handling the seed. Bonuses are provided for higher than average production of foundation seed stocks.

The Ohio Hybrid Seed Corn Producers maintain at Croton, Licking County, Ohio, a two-story, hollow tile, seed warehouse. A bin-type dryer and excellent special equipment are owned by the organization for drying, shelling, grading, storing, and distributing the seed stocks. To date the organization has had to borrow no money and even has a balance to finance operations until such seed stocks distribution and sales collections are initiated in January 1938. Final payments on contracts for seed produced in 1937 are due on April 1, though the contract growers are allowed a 6% per annum carrying charge from October 1 to April 1.

Most of the members have indicated those hybrids for which they wish to have the parent single crosses. However, as certain new hybrids are coming into prominence, shifts may be made by those desiring to do so, insofar as seed stocks permit. Seed stocks are to be distributed at a determined price per 1,000 viable kernels. The number of viable seeds per pound is calculated and appears on the tag attached to each lot of foundation seed. Such a method is far superior to price per pound for it automatically makes adjustments for variations in

sizes of seed and viability of different inbred lines and single crosses. The producer can at once calculate the number of pounds to plant per acre to secure the desired stands in his crossing plats.

Because of the favorable experiences of 1937, certain simplifications can be made in the program of the organization for 1938. Fewer plats will be required, especially for isolated inbred lines. For each inbred line two or three such plats were produced in 1937, and most of them came through successfully so that an abundance of seed is available for 1938 and future years. Because of probable reserve supplies of certain single crosses, the number of such plats may be reduced. There will also be a tendency to increase the size, but reduce the number, of crossing plats for other single crosses.

It will also be the policy of the organization to go even farther than certification regulations specify in use of hand-pollinated seed of inbred lines and in isolation requirements. Close observance of these procedures will facilitate the work of the organization and eliminate many of the possible sources of contamination of seed stocks.

For the following reasons, a cooperative seed stocks organization of the type of the Ohio Hybrid Seed Corn Producers functions as an essential and effective aid to the progress of a hybrid corn program such as obtains in Ohio:

1. The production of the numerous kinds of seed stocks is concentrated under the direction of trained personnel and in large enough quantities to cut down overhead costs.
2. Producers, small and large, are assured access to adequate supplies of pure seed of foundation stocks for producing up-to-date, not obsolete, hybrids.
3. The seed stocks can be rigidly controlled. Poor and obsolete ones can be discarded easily since any loss is distributed among the cooperating group.
4. The numerous risks, due to poor pollination, insufficient isolation, drouths, floods, insects, livestock, unavoidable contaminations, etc., are distributed.
5. The accumulation of reserve supplies is facilitated and financed against situations in later years when seed stocks of one or more types might be distressingly short.
6. The group or sub-groups of seed producers can effectively anticipate and plan for the early initiation of production of superior new hybrids.

## PREFERENCES FOR CERTAIN GENETIC STRAINS OF CORN EXHIBITED BY ANIMALS<sup>1</sup>

E. ROBERTS, J. R. HOLBERT, AND J. H. QUISENBERRY<sup>2</sup>

**D**URING storage certain strains of corn differing genetically were consistently badly damaged by mice and rats, while other strains were damaged only slightly or not at all, though all were equally accessible. Fig. 1 shows two hybrids Ax90 and Ax98, the latter badly damaged. The soiled spots on ears in sample Ax90 were caused by mice, but they preferred Ax98.

The results of a study of six strains of the 1932 crop, recording the number of ears, percentage of ears sampled, and the extent to which the ears were damaged by mice, are given in Table 1. Inbred Hy would probably have been damaged to a much greater extent had not special precautions been taken to protect this strain from the mice. Among the strains, 176A open-pollinated and Inbred Hy of Group I and Hy of Group II are distinctly preferred by mice, while Inbred Leaming suffered no damage.

TABLE 1.—*Damage by mice to various strains of corn of the crop of 1932 in the storage house.*

Strain*	No. of ears tested	Ears damaged %	Percentage of ears damaged to extent of			
			1-5 kernels	6-15 kernels	16-50 kernels	50+ kernels
Group I†						
176A.....	195	19.0	13.3	3.1	1.6	1.0
B-120.....	125	10.4	6.4	2.4	0.8	0.8
Leaming.....	97	0.0	0.0	0.0	0.0	0.0
Hy.....	93	25.7	4.3	3.2	6.4	11.8
Group II†						
RyD <sub>3</sub> .....	500	9.0	7.0	1.6	0.0	0.4
Hy.....	446	36.8	16.2	15.9	2.9	1.8

\*The grain used in this trial consisted of open-pollinated seed of 176A and sib-pollinated seed of all other strains.

†A group consists of lines produced under comparable soil and climatic conditions.

Another study was made of the damage occurring among other strains of the 1935 crop. (See Table 2.) AxHy of Group I, R<sub>4</sub>xHy of Group II, and AxHy of Group III were damaged to a much greater extent than were the other strains, both on the basis of number of ears and the mean number of kernels per ear. With the exception of 90xHy the crosses involving Hy were preferred. The hybrid 90xHy was distinctly lower in preference. A summary of these observations

<sup>1</sup>Cooperative investigation between the Illinois Agricultural Experiment Station, Urbana, Ill., and the Division of Cereal Crops and Diseases, U. S. Dept. of Agriculture. Received for publication December 9, 1937.

<sup>2</sup>Chief in Animal Genetics, University of Illinois; formerly Senior Agronomist, Division of Cereal Crops and Diseases, U. S. Dept. of Agriculture; and formerly Assistant in Animal Genetics, University of Illinois, respectively.

has already been published (6).<sup>3</sup> The preference for Ax90 as noted above was distinctly less than that for Ax98. Mr. C. W. Holmes of Edelman, Illinois, reported in correspondence the feeding of equal

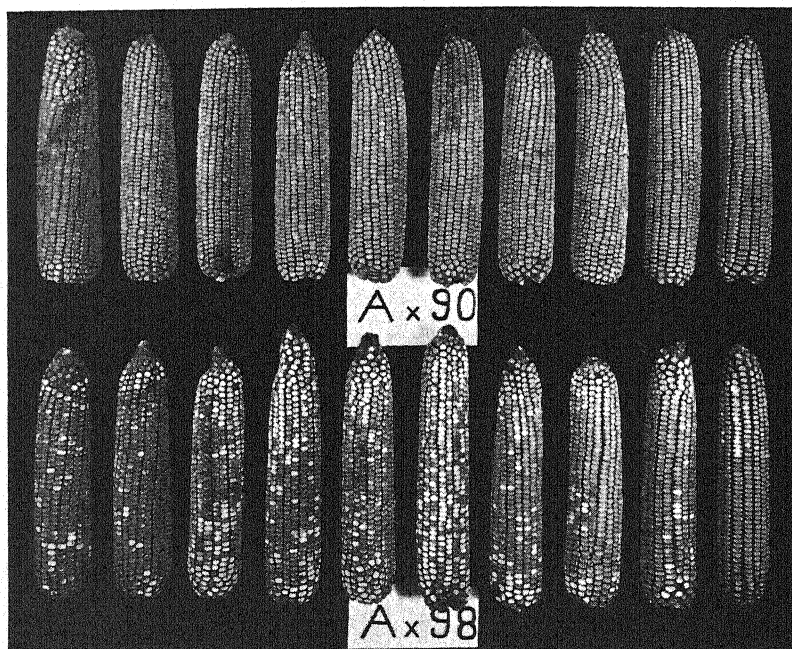


FIG. 1.—Both kinds of corn were equally accessible to mice, but the hybrid Ax98 was much more badly damaged than Ax90, indicating a preference for the former.

TABLE 2.—Damage by mice to various strains of corn of the 1935 crop in the storage house.

Strain	No. of ears observed	Ears damaged %	Mean No. of kernels damaged per ear	Difference	Standard error of difference	D/SE
Group I*						
A×Hy.....	54	98.2	21.6	17.7	8.1	2.19
A×L.....	61	45.9	3.9			
Group II*						
R <sub>4</sub> ×Hy.....	70	98.6	44.2	41.7	7.4	5.64
R <sub>4</sub> ×L <sub>31782</sub>	66	43.9	2.5			
Group III*						
A×Hy.....	65	86.2	39.6	38.4	7.5	5.12
90×Hy.....	58	34.5	1.2			

\*A group consists of lines produced under comparable soil and climatic conditions.

<sup>3</sup>Figures in parenthesis refer to "Literature Cited", p. 159.

quantities of 317x540 and 317x90 to swine and that they consumed all of 317x540 before eating any of 317x90. Mr. Holmes knew nothing of our work on preferences.

In a laboratory test with mice in 1933, using corn produced in 1932, three ears of each of nine strains [inbred lines A, B, Hy, IB, L, R<sub>4</sub>, RyD<sub>3</sub>, and three-way crosses (Ax C<sub>2</sub>)xL, and (HyxR<sub>4</sub>)xL] were placed in a circular cage as shown in Fig. 2, so that any two ears of the same strain were separated by eight ears of the other strains. Circular cages were used in this and other tests in order that position in the cage would not be an interfering factor. Table 3 summarizes weights of grain eaten and kernels damaged. Strain IB is the one distinctly preferred by the animals. A test was made with 12 mice, using inbred lines A, B, Hy, L, R<sub>4</sub>, and RyD<sub>3</sub>, with only one ear of each strain. The test lasted 5 days. Table 4 gives the results. For strain B a strong preference was indicated. In the experiment where B and IB both were included (Table 3), B was less preferred by the animals than was IB.

TABLE 3.—*Summary of damage to whole ears of corn (1933) two tests with six mice each, 6-day periods.*

Strain	Weight of grain eaten, grams			Total No. kernels	Damaged kernels	
	Test 1	Test 2	Total		No.	%
A†.....	5.5	6.9	12.4	2,792	178	6.4
B†.....	10.8	18.5	29.3	4,875	607	12.5
Hy†.....	9.9	32.2	42.1	2,147	790	36.8
IB†.....	28.0	168.1	196.1	3,907	1,813	46.4
L†.....	3.2	9.1	12.3	2,014	61	3.0
R <sub>4</sub> †.....	5.1	7.0	12.1	2,594	179	6.9
RyD <sub>3</sub> †.....	5.9	9.7	15.6	3,296	213	6.5
F <sub>1</sub> (AxC <sub>2</sub> )xL.....	14.6	8.5*	23.1*	3,942	626*	15.9
F <sub>1</sub> (HyxR <sub>4</sub> )xL.....	37.4	39.8*	77.2*	3,434	876*	25.5

\*Only one ear of this variety in test 2.

†Sib-pollinated seed used.

TABLE 4.—*Summary of damage in two tests in which 12 mice were fed for 5-day periods.*

Strain*	No. of observed kernels	Kernels damaged		Weight of grain eaten, grams
		No.	%	
A.....	405	55	13.6	4.5
B.....	712	383	53.8	138.5
Hy.....	409	11	2.7	14.5
L.....	352	2	0.6	2.5
R <sub>4</sub> .....	310	24	7.7	6.5
RyD <sub>3</sub> .....	479	5	1.0	2.5

\*Sib-pollinated seed used in each case.

In 1934 three tests of two cages each with two ears of each of four inbred lines (Hy, K, R<sub>4</sub>, and 90) in each cage were made with mice, each cage containing six mice with the exception of one which had

five. As in other tests the samples of corn belonging to the same strain were separated by placing samples of the other strains between the two of the same strain. Table 5 gives the results. Kernels were pulled from the ears with little damage to the kernels. Hy had only 3.1% of the kernels missing while 90 had 56.0%, but of the kernels remaining on the ears 32.5% of Hy were damaged and of 90 only 0.26%. Distinct preference was again exhibited in these tests.

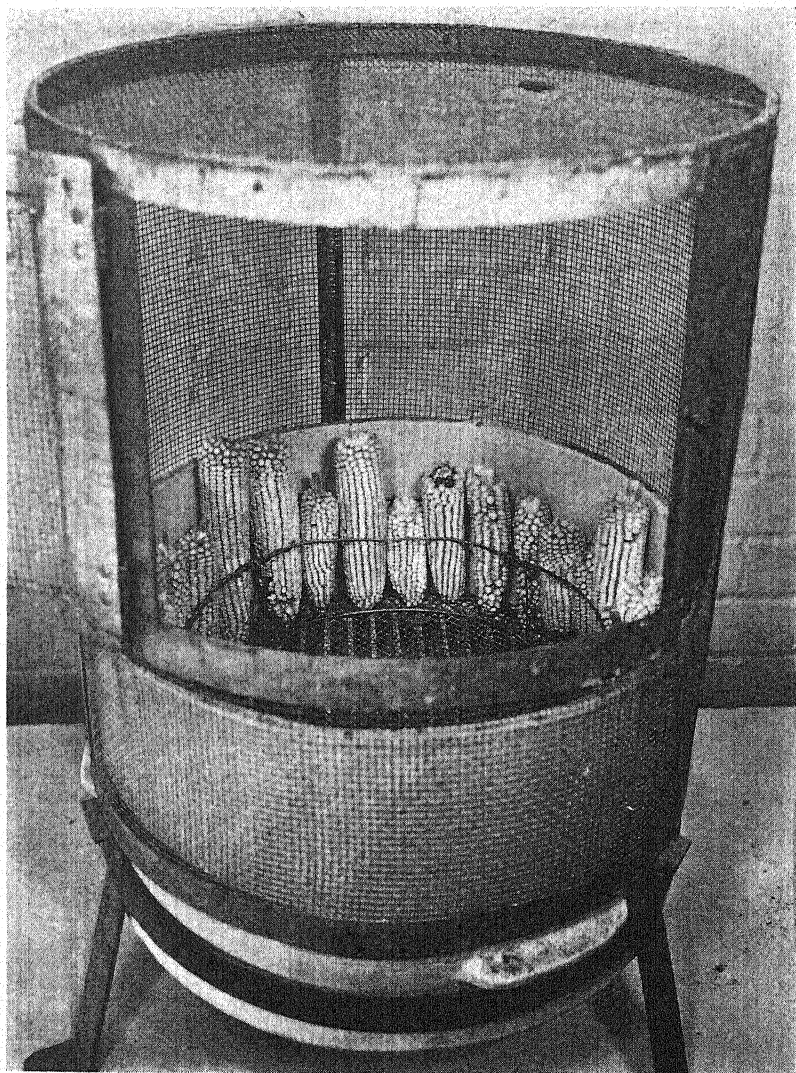


FIG. 2.—Method of arranging ears of corn in circular cage.



TABLE 5.—*Tests of four strains of corn with mice (1934).*

Strain*	No. of ears observed	No. of kernels observed	Kernels missing		Damaged kernels among those remaining	
			No.	%	No.	%
Test I						
Hy.....	4	1,807	7	0.39	814	45.22
K.....	4	1,138	231	20.30	3	0.33
R <sub>4</sub> .....	4	2,027	252	12.43	281	15.84
90.....	4	2,209	1,170	52.97	3	0.29
Test II						
Hy.....	2	1,000	2	0.2	686	68.74
K.....	2	491	95	19.35	2	0.51
R <sub>4</sub> .....	2	823	303	36.82	44	8.46
90.....	2	1,024	790	77.15	3	1.28
Test III						
Hy.....	4	1,895	75	3.96	3	0.16
K.....	4	1,029	485	47.13	2	0.37
R <sub>4</sub> .....	4	1,798	1,123	62.46	23	3.41
90.....	4	1,938	936	48.30	0	0.0
Total						
Hy.....	10	4,702	84	3.11	1,503	32.55
K.....	10	2,658	811	30.51	7	0.38
R <sub>4</sub> .....	10	4,648	1,678	36.10	348	11.72
90.....	10	5,171	2,896	56.00	6	0.26

\*Sib-pollinated seed used in each case.

Ear corn was also used with rats, but the test was not very satisfactory because the rats pulled the grains from the cob, eating largely the germs. The following records were made:

A—damage slight, 1.5 grams of kernels destroyed  
 B—damage slight, 4.5 grams of kernels destroyed  
 Hy—damage slight, 1.0 grams of kernels destroyed  
 L—damage severe, 43.0 grams of kernels destroyed  
 R<sub>4</sub>—damage slight, 3.0 grams of kernels destroyed  
 RyD<sub>3</sub>—damage complete, 144.0 grams of kernels destroyed

Several tests were made with rats, using ground corn. This made possible more accurate measurements of the amounts eaten. The feed dishes were placed in circular cages as shown in Fig. 3. The order of the dishes was changed when a trial was repeated. One trial consisted of two cages with nine strains of corn [inbred lines A, B, Hy, IB, L, R<sub>4</sub>, and RyD<sub>3</sub> and three-way crosses (AxC<sub>2</sub>)xL, and (HyxR<sub>4</sub>)xL], with one rat in each cage. Each rat was used for two 6-day periods. The results are given in Table 6. Strains (AxC<sub>2</sub>)xL and (HyxR<sub>4</sub>)xL were consistently eaten in preference to the other strains. In another test involving two rats with these two strains and IB left out, the average amounts of meal (in grams) eaten were as follows: A, 6.3; B, 39.8; Hy, 0.8; L, 4.7; R<sub>4</sub>, 9.0; RyD<sub>3</sub>, 18.3. In this test the greatest preference is shown for B, as was also shown by mice in Table 4.



Table 7 gives the amounts of corn eaten when seven inbred lines (A, B, Hy, K, L, RyD<sub>3</sub>, and 90) were in the test at the same time.

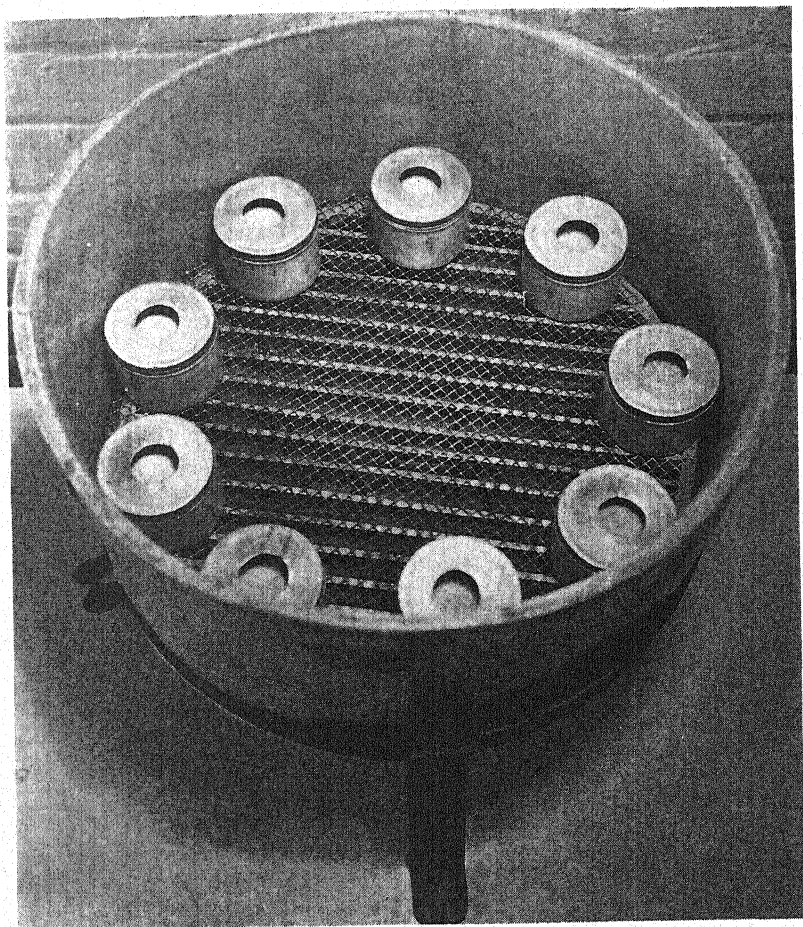


FIG. 3.—Arrangement of feed dishes in tests on the preference of animals for different genetic strains of corn.

RyD<sub>3</sub> was distinctly preferred with B in second place. Fig. 4 shows the total amounts eaten. A summary of these trials was published by Roberts and Quisenberry (5). The records were also studied on the basis of the average amount in grams eaten daily per 100 grams of weight of rat. These averages with probable errors are given in Table 8.

These seven inbred lines were also tested three at a time, the results of these tests being given in Table 9. With A, B, and Hy in combination, A was preferred; with K, L, and RyD<sub>3</sub>, RyD<sub>3</sub> was preferred; and with A, RyD<sub>3</sub>, and 90, RyD<sub>3</sub> was also preferred.

TABLE 6.—*Amounts of ground corn eaten by rats 3 and 4 on two successive trials (1933).*

Strain	Grams of corn eaten by Rat No. 3			Grams of corn eaten by Rat No. 4			Average amount for both rats, grams
	Trial 1	Trial 2	Ave.	Trial 1	Trial 2	Ave.	
A*.....	1.5	2.0	1.75	1.5	0.0	0.75	1.25
B*.....	3.0	5.0	4.00	2.5	0.5	1.50	2.75
Hy*.....	0.5	0.5	0.50	1.5	1.0	1.25	0.88
IB*.....	6.5	11.5	9.00	6.0	13.0	9.50	9.25
L*.....	0.5	5.5	3.00	7.5	6.0	6.75	4.88
R <sub>4</sub> *.....	0.5	0.5	0.50	1.5	0.0	0.75	0.63
RyD <sub>3</sub> *.....	6.5	1.5	4.00	4.5	3.5	4.00	4.00
F <sub>1</sub> (A×C <sub>2</sub> )×L...	68.5	24.0	46.25	77.0	22.0	49.50	47.88
F <sub>1</sub> (Hy×R <sub>4</sub> )×L...	12.5	22.7	17.60	39.5	51.0	45.25	31.43

\*Sib-pollinated seed used.

TABLE 7.—*Summary of amounts of seven strains of ground corn eaten by rats (1934).*

Strain*	No. of tests	No. of rats	Total days	Total eaten in grams	Eaten daily per rat in grams
A.....	13	36	37	231	1.04
B.....	13	36	37	478	2.15
Hy.....	13	36	37	237	1.07
K.....	13	36	37	429	1.93
L.....	13	36	37	350	1.58
RyD <sub>3</sub> .....	13	36	37	1,307	5.89
90.....	13	36	37	181	0.82

\*Sib-pollinated seed used in each case.

TABLE 8.—*Means and probable errors of amounts of ground corn eaten by rats per 100 grams live weight computed from the data in Table 7.*

Strain*	Average eaten daily in grams per 100 grams rat	Probable error
RyD <sub>3</sub> .....	3.69	0.224
B.....	1.38	0.214
K.....	0.98	0.200
L.....	0.78	0.171
Hy.....	0.70	0.167
A.....	0.55	0.119
90.....	0.52	0.062

\*Sib-pollinated seed used in each case.

The significance of the differences between amounts of RyD<sub>3</sub> and B eaten is  $P = .9934$  or 1:151 in favor of RyD<sub>3</sub>. Between RyD<sub>3</sub> and 90  $P = .9991$  or 1:1110 in favor of RyD<sub>3</sub>.

When RyD<sub>3</sub>, K, and L were together in the test, for the difference in amounts eaten per day between RyD<sub>3</sub> and L,  $P = .999$  or 1:999 in favor of RyD<sub>3</sub>.

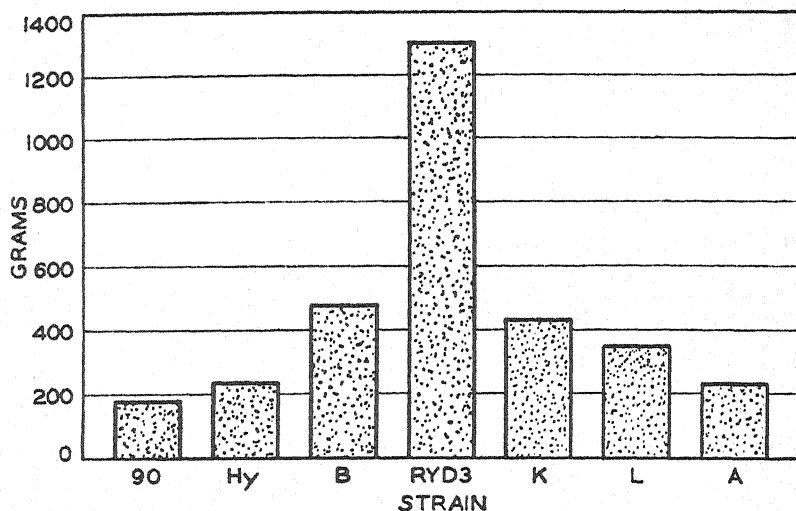


FIG. 4.—Variations in amounts of different strains of ground corn eaten by rats. The animals showed a distinct preference for strain RYD<sub>3</sub>, of which 1,307 grams were consumed. Next in popularity was strain B, with 477.5 grams consumed. Strain 90, with only 181 grams eaten, was the least popular.

TABLE 9.—Summary of amounts of ground corn eaten by rats with three strains of corn present at a time (1934).

Strain*	No. of tests	No. of rats	Total days	Total eaten in grams	Eaten daily per rat in grams
A.....	2	6	7	152	3.61
B.....	2	6	7	116	2.75
Hy.....	2	6	7	65	1.55
K.....	2	6	7	50	1.19
L.....	2	6	7	74	1.75
RyD <sub>3</sub> .....	2	6	7	203	4.83
A.....	2	6	6	75	2.08
RyD <sub>3</sub> .....	2	6	6	197	5.46
90.....	2	6	6	55	1.51

\*Sib-pollinated seed used in each case.

With A, RyD<sub>3</sub>, and 90 together, considering the amounts of RyD<sub>3</sub> and 90 eaten, the significance of the difference is  $P = .9966$ , or 1:293 in favor of RyD<sub>3</sub>.

The 1935 tests with rats, using ground corn, are summarized in Table 10. In all tests the crossed strains in which inbred 90 appears, with the exception of one, less was eaten. Inbred 90 was also less preferred than 98 and RyD<sub>3</sub>. Inbred A was also less preferred than were some of the other strains. A summary of these tests has already been published (6).

TABLE 10.—*Summary of amounts in grams of ground corn eaten by rats with strains A, 90, 98, RyD<sub>3</sub>, A×98, RyD<sub>3</sub>×A, RyD<sub>3</sub>×90, and A×90 in various combinations (1935).*

Strain	No. of rats	No. of tests	Total days	Total eaten in grams	Average eaten per day, grams
A*.....	6	2	6	91	2.53
90*.....	6	2	6	65	1.81
98*.....	6	2	6	137	3.81
A×90.....	6	2	6	95	2.64
A×98.....	6	2	6	86	2.39
A*.....	6	2	6	45	1.28
RyD <sub>3</sub> *.....	6	2	6	392	10.89
90*.....	6	2	6	53	1.47
98*.....	6	2	6	196	5.44
A×90.....	6	2	6	122	3.39
A×98.....	6	2	6	199	5.53
RyD <sub>3</sub> ×A.....	6	2	6	190	5.28
RyD <sub>3</sub> ×90.....	6	2	6	62	1.72
A×90.....	6	2	6	224	6.22
A×98.....	6	2	6	304	8.44

\*Sib-pollinated seed used.

Reasons for the preferences exhibited in these tests have not been studied. Studies of this phase of the problem are very important and should include the morphological structure of the kernel, especially differences in hardness; and chemical composition with particular reference to differences in odor and vitamin content. Also possible differences in animals should be considered. In some of our tests a few animals were found which seemed to exhibit no preference, eating from all the strains indiscriminately, while others had distinct preferences.

Hereditary differences in man in respect to the taste of phenyl-thio-carbamide have been reported by Blakeslee and Fox (1). To some this chemical is bitter, sour, sweet, or salty and to others it is tasteless.

Harris, et al. (4), have shown that rats can discriminate between diets containing and lacking vitamin B. Franke and Potter (3) demonstrated that rats were able to detect and differentiate between small quantities of selenium in foodstuffs.

Dove (2) from a long series of experiments with the rat, chick, and dairy calf concluded that nutritive instincts, manifested in a choice of food, are characteristics of the individual; that these instincts vary from individual to individual; and that these instincts are due principally to innate differences.

It is well known that animals possess a preference for foods derived from certain species of plants and it is also probable that differences exist among strains of the same species causing the expression of distinct preferences. The results of the observations and experiments with different genetic strains of corn reported in this paper suggest

that palatability or preferences exhibited by animals should also be considered in plant improvement.

### SUMMARY

The results of feeding trials using genetically different strains of corn suggest very definitely that both mice and rats exhibit a preference for certain strains. One observation with swine also indicates a distinct preference.

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## NOTES

GREEN NEEDLE GRASS, *STIPA VIRIDULA*, FOR EROSION CONTROL

GREEN needle grass, *Stipa viridula* Trin., is proving to be one of the most valuable native grass species for erosion control purposes in the northern Great Plains area. It grows under a wide range

of soil and climatic conditions and appears to be extremely drouth resistant.

It has been the opinion of ecologists that this species required a rather favorable habitat, being a local dominant in areas receiving more moisture. This conception may have occurred since it is commonly found, under natural conditions, in coulees, swales, and low spots.

In studying drouth survival of different grass species at various stations<sup>1</sup> in the northern Great Plains region during the past two years, *Stipa viridula* was found to have been extremely drouth resistant.

This species has a medium fine fibrous root system (Fig. 1) with a lateral spread of from 6 to 10 inches and a maximum penetration of about 50 inches.<sup>2</sup> Most of the roots are confined to the upper 36 inches. Being a bunch grass, *Stipa viridula* is not as efficient a soil binder as a sod-former.

Seeding and harvesting can be handled with the ordinary farm machinery. Planting can be accomplished with an ordinary grain drill. The seed should not be planted too deeply, from  $\frac{1}{4}$  to  $\frac{1}{2}$  inch being recommended. To date, late fall or early spring plantings have given the best results. Seed can be harvested with a combine or stripper or cut with a mower and threshed.

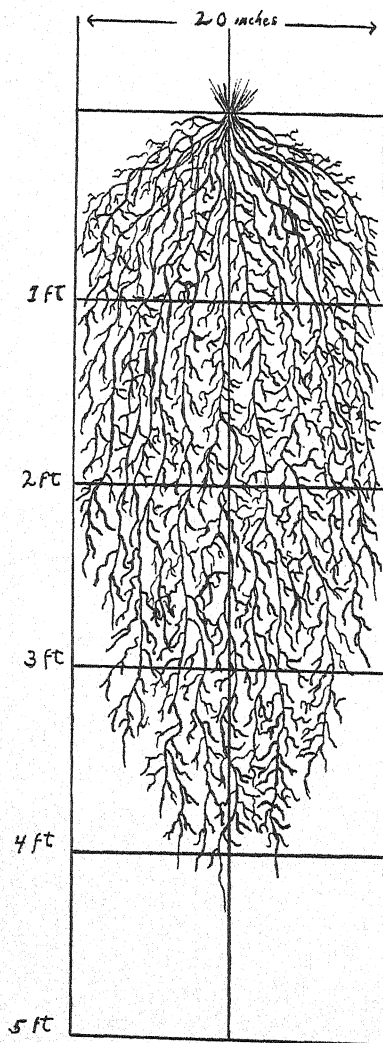


FIG. 1.—Root system of *Stipa viridula*.

<sup>1</sup>Ardmore, Brookings, Cottonwood, and Highmore, South Dakota; Dickinson Mandan, and Fargo, North Dakota; and Archer, Wyoming.

<sup>2</sup>From studies made in Kimball County, Nebraska.

Seed germination percentages are fairly high and the seedlings are extremely vigorous. They can withstand drouth and considerable sandblasting without serious damage.

The principal objection to this species is the uneven ripening of the seed on the panicle. The seed at the end ripens and shatters while that at base will still be green. No doubt this could be overcome through selection, thereby ultimately obtaining a strain or selection which would ripen the seed evenly. As with most native species, *Stipa viridula* shows wide variations in seeding and vegetative characters.

Palatability of *Stipa viridula* is high, being estimated at 70% by J. T. Sarvis of the U. S. Field Station, Mandan, North Dakota, and the U. S. Forest Service.—B. IRA JUDD, *Tempe, Arizona*.



### A DEVICE FOR THE RAPID COLLECTION OF SURFACE-INCH SOIL SAMPLES

THE surface inch of soil on mountainous range watershed lands in the West commonly contains much more organic matter than do the deeper layers. Because this concentration of organic matter greatly influences percolation of water and because erosion losses are largely surface losses, it is essential in many range-erosion investigations that the surface inch (or at least a shallow layer) be isolated and evaluated.

A simple and inexpensive shovel device that facilitates the rapid and accurate sampling of the surface inch of soil has been developed by the Intermountain Forest and Range Experiment Station. This shovel will likely be found useful to many workers in the field who have experienced difficulty in obtaining surface samples with the conventional types of geotomes or augers ordinarily used for sampling soils.

The surface-inch sampler, as shown in Fig. 1, is made of sheet metal and the cutting edge sharpened. Automobile fender steel of 18 to 22 gage has been found well adapted for this construction and is sufficiently strong to withstand driving when necessary in dry soil.

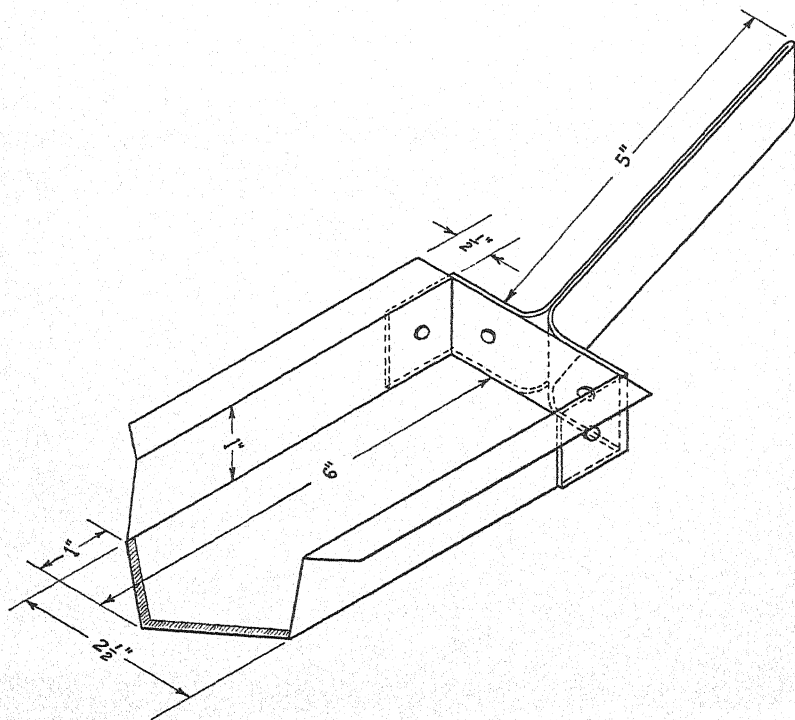


FIG. 1.—Diagram of hand shovel made of sheet metal for taking surface soil samples. The dimensions given are for surface-inch samples.

Samples are taken by pushing the shovel into a vertical cut in the soil in such a position that the projecting flanges are flush with the soil surface, thus removing measured surface-inch samples. By completely filling the shovel at each sampling, samples of approximately uniform volume may be secured. This allows representative composites to be made.

During the past season approximately 6,000 soil samples have been taken by the authors and other members of the Intermountain Forest and Range Experiment Station with this device. Analyses of these samples have given a clear-cut picture of soil losses caused by accelerated erosion. The use of the device also helps in getting uniformity of soil samples taken by different investigators.—LOWELL WOODWARD and D. A. ANDERSON, *Intermountain Forest and Range Experiment Station, Ogden, Utah.*

### A SIMPLE MACHINE FOR CLEANING SMALL GRAIN NURSERY SAMPLES

**A**N efficient, inexpensive, and easily constructed seed cleaner, as shown in Fig. 1, is being used successfully for cleaning nursery samples at the Southern Great Plains Field Station, Woodward, Okla. The cleaner is almost mixture proof, having few places where a kernel may lodge and these being beveled and visible, the hazard of mixtures is minimized. The machine is easily and quickly adapted to cleaning different cereals by adjusting the position and speed of the fan and the slope of the metal plates. Three shakers, with screen bottoms of different mesh, for use with various grains serve to separate the coarser particles of straw from the grain, leaving mostly chaff and dust to be blown out by the fan.

Material to construct the cleaner will cost from \$3 to \$5, excluding cost of fan, the latter being available at most stations. The three shakers (Fig. 1, a), are fitted with  $\frac{3}{8}$ -inch,  $\frac{1}{4}$ -inch, and  $\frac{1}{8}$ -inch hail screen. An 18-gage galvanized metal plate, held at any desired angle by thumb screw (Fig. 1, C), spreads the grain into a thin sheet and regulates the rate of fall. A second metal plate (Fig. 1, h), projecting any desired distance and angle, is held in place by thumb screw (Fig. 1, i) and aids in regulating the amount of material blown from the grain. Quarter-round is dadoed  $\frac{1}{4}$  inch above the pan (Fig. 1, n) to prevent kernels from falling beside or behind the pan. Two pans may be constructed to replace one another when re-cleaning is necessary. A three-speed, 14-inch electric fan is bolted to slide (Fig. 1, l). A thumb screw (Fig. 1, j) holds the slide at any desired distance from the box, thus further controlling the air passing through the box. A smaller fan might suffice for a box of this size.

In operation the grain is poured in at the top, the shaker is agitated by hand, the grain falls through the air blast, and the cleaned grain is removed in the pan (Fig. 1, n).—V. C. HUBBARD, *Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C.*

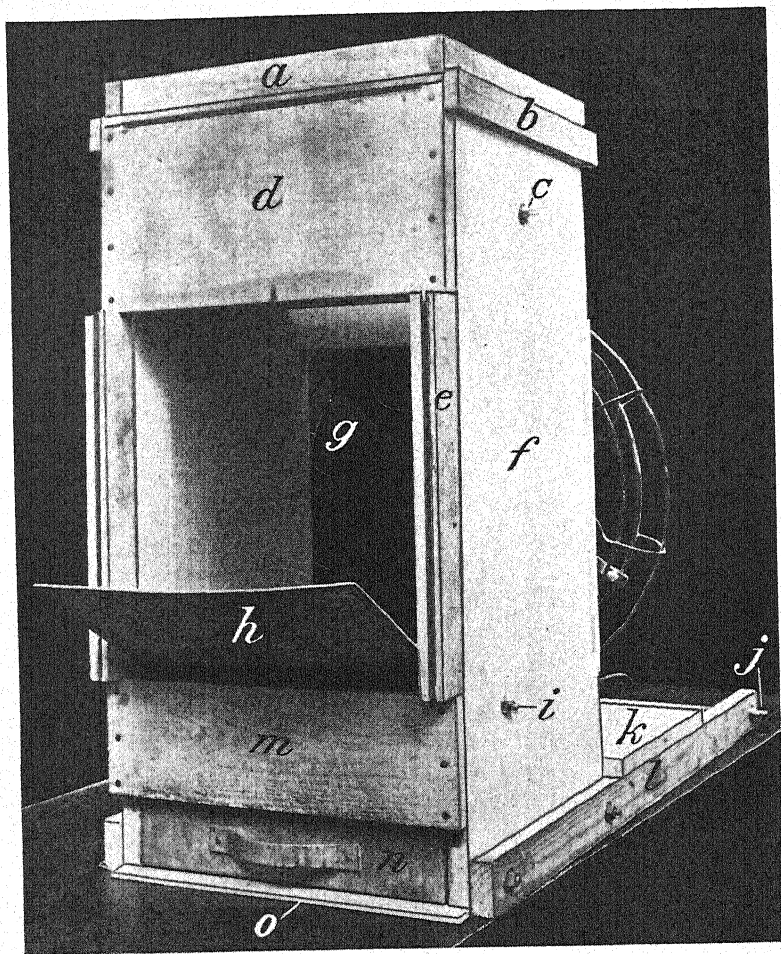


FIG. 1.—Machine for cleaning small grain samples. (a) Shaker,  $1\frac{1}{4}$  inches deep and  $11\frac{1}{2}$  inches square; (b)  $1 \times 2$  inch  $\times$   $13\frac{3}{4}$  inch sides serve as guides for the shaker, a; (c) thumb screw, 4 inches from top and  $6\frac{1}{2}$  inches from the front of box, holding metal plate in place; (d)  $1 \times 6$  inches  $\times$   $13\frac{3}{4}$  inches; (e)  $1 \times 1\frac{5}{8}$  inches  $\times$  12 inches (may be any width necessary to prevent kernels rolling off sides of plate); (f) side of box,  $1 \times 11\frac{5}{8}$  inches  $\times$   $24\frac{5}{8}$  inches; (g) opening  $11\frac{5}{8}$  inches wide and 12 inches high; (h)  $11\frac{5}{8} \times 14$  inch plate of number 18-gage galvanized metal enters box freely but snugly enough to be held in place by tightening thumb screw, i; (i) thumb screw, 6 inches from bottom and  $4\frac{1}{2}$  inches from box front (holds metal plate, h, projecting at any desired distance and angle); (j) thumb screw holds platform, k, in place (arms, l, are tightened on cleats nailed to under side of platform, k); (k),  $11\frac{5}{8} \times 14\frac{3}{4}$  inch platform for supporting fan; (l)  $1 \times 1\frac{5}{8}$  inch  $\times$  34 inch strips support and serve as slides for platform, k; (m)  $1 \times 4 \times 13\frac{3}{4}$  inches; (n) pan of 18-gage galvanized metal,  $2\frac{7}{16}$  inches high in front and  $2\frac{2}{16}$  inches high at the back and  $11\frac{1}{4}$  inches square (box opening for pan is  $2\frac{5}{8} \times 11\frac{5}{8}$  inches); (o)  $\frac{1}{4} \times 13\frac{3}{4} \times 14$  inches panel-board forms bottom of box and slide for pan (measurements of back of box are identical with those of front except that the bottom board, having no pan opening, is  $1 \times 6\frac{5}{8} \times 13\frac{3}{4}$  inches). Photograph by courtesy of L. F. Locke and E. W. Johnson, Division of Dry Land Agriculture, U. S. Dept. of Agriculture.

## BOOK REVIEWS

## POTASH DEFICIENCY SYMPTOMS

*By Oskar Eckstein, Albert Bruno, and J. W. Turrentine. Berlin; Verlagsgesellschaft Fur Ackerbau M. B. H. 248 pages, illus. 1937. \$2.25.*

THIS book, representing the cooperative effort of the German Potash Syndicate, the French Potash Society, and the American Potash Institute, is designed to assist agriculturists in determining whether or not their soils contain a sufficient supply of available potash. Three languages, *viz.*, German, French, and English, are used in this volume.

A chart is given near the front of the book illustrating clearly the fact that such plant nutrients as nitrogen, phosphoric acid, and potash are removed from the soil in varying proportions by the different cultivated plants. Lengthy discussions are not included as it is realized that colored illustrations of potash deficiency symptoms in plant parts convey a clearer impression than words. The book presents the principal facts concerning plant abnormalities resulting from a lack of available potash.

The volume consists of two parts, *viz.*, general symptoms of potash deficiency, and potash deficiency symptoms on various cultivated crops. The first part deals with the external plant symptoms of potash deficiency as well as those modifications of the inner structure of the leaf, root, blossom, and fruit which result from a lack of potash. It also includes a discussion of the secondary effects of potash deficiency, such as its influence on the resistance of plants to diseases, pests, and unfavorable climatic factors. The second part describes in detail potash deficiency symptoms in maize, fruit trees, and vines, and contains many colored illustrations of characteristic potash deficiency symptoms in various cultivated crops. The volume contains a valuable study of deficiency symptoms, strikingly illustrated. (H. P. C.)

## SOILS AND SOIL MANAGEMENT

*By Charles Ernest Millar. St. Paul, Minn.: Webb Book Publishing Co. Ed. 2. 477 pages, illus. 1937. \$2.*

THIS revision, like its predecessor, is admirably designed as a stimulating text for elementary soils courses and for the lay reader who has more than a casual interest in the soil.

The book is copiously illustrated and each chapter is followed by a number of "Problems" based on the preceding subject matter. A list of pertinent references is also appended to each chapter. A glossary of technical terms encountered in the text, together with an excellent index, add materially to the usefulness of the book for the lay reader. (J. D. L.)

## MOTHER EARTH

*By Gilbert Wooding Robinson. London: Thos. Murby. VIII 202 pages, illus. 1937. 5/6.*

THIS unique little book departs from the conventional form of book making to the extent that the seventeen sections of the text instead of being designated as chapters are termed "letters" on the soil addressed by the author, who is Professor of Agricultural Chemistry at University College of North Wales, to Professor R. G. Stapledon, Director of the Welsh Plant Breeding Station.

In terms intelligible to the general reader, the author attempts to set forth modern views on soils and their implications for present and future agriculture. "The affairs of the soil," writes the author in a preliminary statement to the "Gentle Reader", "may not have the strange magnificence of the outer universe or the curiosity of the inner recesses of the atom; but they touch our daily life more intimately," and it is the hope of the author that this book may aid the general public to think rightly on matters of grave concern to all—the future of the soil.

In a letter headed "Corruptio Optimi Pessima", the author deals briefly but comprehendingly with soil problems in the United States and the efforts that are being made to meet them. In the light of these problems he then proceeds to build up his hypothesis that the salvation of agricultural soils rests in the periodical renewal of their fertility under grass.

This book will be read with interest and profit by everyone actively engaged in soil conservation or seriously concerned with the future of the arable soils of the world. (J. D. L.)

## THEORY AND PRACTICE IN THE USE OF FERTILIZERS

*By Firman E. Bear, New York: John Wiley & Sons, Inc. Ed. 2. 360 pages, illus. 1938. \$4.*

THIS second edition represents a considerable revision of the first edition published in 1929. The chapters on nitrogen fertilizers, potash fertilizers, mixed fertilizers, principles of fertilizer practice, selection of fertilizers, application of fertilizers, controlling the soil reaction, and supplying organic matter have been largely rewritten. A new chapter dealing with the "trace" elements has been added. Changes and additions introduced involve consumption of fertilizers in the United States and Europe, availability and value of nitrogen carriers, equivalent acidity and basicity of fertilizers, calcined phosphate, fertilizer recommendations for corn and cotton, tests for soil deficiencies, and selection and application of fertilizers.

The extensive studies and wide experience of the author in the fertilizer field are reflected in the character of the treatise. The field is well covered and still the book has been kept within reasonable size so that it may be used advantageously as a classroom text or by the busy practical or technical man. One might like to have the matter of reactions between fertilizer constituents and soil minerals discussed at greater length, especially in relation to fixation and soil reaction. The

material included has been well selected and arranged, and the method of presentation is clear and concise. The treatment is scientific but still quite understandable by the non-technical man. The brief historical treatment of the more important subjects should be stimulating to the thinking of both the student and man in practical work.

The book fills a real place in our fertilizer literature, and should serve as an excellent classroom text in many schools as well as a handy guide for the practical and technical man interested in fertilizer use. Apparently the editor failed to revise the paging in the table of contents so as to correspond with the changes in chapter lengths. (E. T.)



## AGRONOMIC AFFAIRS

## A DIGEST OF WORLD PASTURE RESEARCH LITERATURE

**D**R. A. J. Pieters, Principal Agronomist, Division of Forage Crops and Diseases, U. S. Dept. of Agriculture, has compiled a digest of world pasture research literature exclusive of the continental United States and Canada. This supplements his digest of pasture research literature in the United States and Canada for the period of 1885 to 1935 already noted in the pages of this JOURNAL (Vol. 28, page 421).

The present Digest is in mimeograph form and contains 1,282 references arranged by country of origin. A list of abbreviations used in the citations and a subject index are included.

It is pointed out that the Digest does not purport to be a complete bibliography of pasture research literature outside the United States and Canada, but it is believed that enough is presented to serve as a cross-section of foreign pasture research of most interest to American students.

## RANGE PLANT HANDBOOK

**T**HIS Handbook, now obtainable from the Superintendent of Documents, U. S. Government Printing Office at \$2.50 a copy, has been prepared under the supervision of W. A. Dayton, Senior Forest Ecologist, Range Forest Investigations, U. S. Dept. of Agriculture, primarily to meet the demand among field officers of the Forest Service for information on the identity of common plants on the national forest ranges, the value of these plants as forage for livestock and wildlife and as soil-binders in erosion prevention and control operations, and for concise information on range management.

The Handbook contains 841 pages of text and index, the latter also serving as a check list. There are 339 write-ups containing notes on about 300 "key" species and 210 genera of range plants, with secondary notes on over 500 additional species. The book is copiously illustrated, including 18 color plates. A unique feature is the tying in of a key diagnostic text description to each appropriate part of the plant in the illustrations, adding much to the usefulness of the latter.

## NEWS ITEMS

ANNOUNCEMENT has been made of the appointment of Dr. E. C. Auchter, formerly head of the Division of Fruit and Vegetable Crops and Diseases of the Bureau of Plant Industry of the U. S. Dept. of Agriculture, as Chief of the Bureau of Plant Industry, following the resignation of F. D. Richey who is now engaged in professional corn breeding.

DR. S. F. THORNTON, formerly Soil Chemist at the Purdue University Agricultural Experiment Station, resigned that position on February 1 to become Agronomist for the F. S. Royster Guano Company of Norfolk, Va.

DR. GEORGE D. SCARSETH, Associate Professor of Soils and Associate Soil Chemist at the Alabama Polytechnic Institute, has been appointed Soil Chemist in the Agronomy Department of the Purdue University Agricultural Experiment Station, with the rank of Associate Professor, filling the position made vacant by the resignation of Dr. S. F. Thornton.

LEO D. WHITNEY, Assistant Agronomist of the University of Hawaii, died on November 7, 1937, following a brief illness. Mr. Whitney dealt chiefly with economic pasture grasses and also made notable contributions to the taxonomy of taro.

### ERRATUM

IN Fig. 2 on page 14 of the January (1938) number of the JOURNAL in the article by A. N. Watson and R. L. Davis entitled, "The Statistical Analysis of a Spacing Experiment with Sweet Corn", the figures for "Total number per acre of marketable ears" on the left-hand margin of the chart are in error. These should read, from top to bottom, 2,400; 2,200; 2,000; 1,800; 1,600; 1,400; and 1,200.

# JOURNAL

OF THE

## American Society of Agronomy

VOL. 30

MARCH, 1938

NO. 3

### THE RELATION OF THE NATIONAL AGRICULTURAL PROGRAM TO AGRONOMIC BETTERMENT<sup>1</sup>

M. A. McCall<sup>2</sup>

THE national agricultural program, developed at first under the Agricultural Adjustment Act and more recently under the Soil Conservation and Domestic Allotment Act, has reached further into the field of agronomy than most of us probably anticipated. What effect will its impacts exert in the betterment of agronomy itself?

The essential features of the A.A.A. program are generally known. Its objectives and its plan of operation are likewise familiar. Plans for 1938 operations have been outlined and discussed on our program during the current sessions of the Society. There is no reason, therefore, to go into these details, or to consider other than some factors directly important to us as agronomists.

The attitude of many agronomists toward A.A.A. activities has been that of the "innocent bystander." This rôle implies some curiosity and more or less mild interest. It is also pertinent to recall that the "innocent bystander" sometimes gets shot. This latter is mentioned merely to emphasize the fact that any enterprise as broad in scope and as active as the A.A.A. sooner or later may strike any one of us in a very direct way. It also has happened before now, in spite of "peace pacts," "neutrality acts," or what have you, that the "innocent bystander" found himself in the thick of things before he realized what had happened.

On the other hand, in the beginning there was good reason for the agronomist to feel somewhat detached from A.A.A. activity. The original avowed purpose of the program was to correct inequalities in farm income and to place the farmer on a more secure economic basis. It dealt with surpluses, crop adjustment and control, prices, income, and other economic factors. Its leaders properly were economists. We as agronomists have been sure from the beginning that agriculture can-

<sup>1</sup>Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Delivered at the general session of the annual meeting of the Society held in Chicago, Ill., December 2, 1937.

<sup>2</sup>Principal Agronomist in Charge of the Division of Cereal Crops and Diseases and Assistant Chief of the Bureau of Plant Industry.

not be brought to a stable economic status unless based on stable productive soils and sound crop practice, but most of us have had other things to do and it has been the line of least resistance to let it go at that. Probably as a result of detachment, many of us, also, have developed an attitude toward the problem and toward the economist strangely like that of the "pure scientist" toward his brother in applied fields. All of which proves nothing, except that as David Harum remarked, "The's as much human nature in some folks as th' is in others, if not more."

Subsequent developments, however, have so changed the original picture that now there is ample reason for a less detached point of view. The change began, in fact, very early in the program. Administrator Tolley of the A.A.A. in his report for 1936 says, "\*\*\* the decision of the Supreme Court in the *Hoosac Mills Case* had the effect of hastening a transition which had long been planned. This was the transition from the temporary emergency phase of the adjustment programs to a long-time phase which would give a larger place to soil conservation and improved farm-management practice."

To us as agronomists, the significance of this shift and of the almost universal acceptance of wise land-use and soil conservation as a fundamental part of any long-time program to promote farm stability, cannot be over-emphasized. Both major political parties have recognized the principle in their platforms. It is one item upon which the farm organizations agree. Such general endorsement suggests that it will remain in the public mind as an essential part of any permanent Federal agricultural action program.

Soil conservation in its broad sense includes practically everything for which we agronomists have stood in the way of sound land and crop use, improvement, and management. Any activity that promotes universal recognition of soil conservation in this sense is making a real contribution to agronomy. None of us would credit the A.A.A. with discovering the importance of this kind of soil conservation in a stabilized farm program. On the other hand, I think we will all agree that the A.A.A., in focusing public attention on the necessity for soil conservation in developing farm economic stability, has made a most important contribution to agronomic betterment, the total extent of which only time can determine.

As agronomists, we naturally are interested in the direct tangible improvements in soil and crop management which have come about as a result of the A.A.A. program. A summary of the uses made of land diverted from surplus crops during the years of operation under the Agricultural Adjustment Act up to January 6, 1936, is given in the report of former Administrator Davis for 1933 to 1935. There were 35,767,899 acres shifted from the production of cotton, corn, wheat, and tobacco in 1934, and 30,336,838 acres in 1935. Studies made in 1934 showed that a majority of Corn Belt farmers used this diverted acreage for establishing alfalfa, sweet clover, and timothy, or elected to use old sods as contract acreage, allowing them to lie unplowed. Estimates for Ohio, Indiana, Illinois, Iowa, Missouri, and Nebraska showed that in these states 9,264,698 contracted acres were used approximately as follows:

"About one-third for new seedings of meadow and pasture crops, chiefly alfalfa, sweet clover, and clover and timothy.

"About one-fourth in old meadow crops left unplowed (clover, timothy, sweet clover, bluegrass pasture).

"About one-third planted to emergency forage crops (soybeans, millet, Sudan grass, forage sorghums, fodder corn).

"About one-twelfth, used for controlling weeds, was fallowed or left idle."

Data for 1936, the first year of A.A.A. operations under the Soil Conservation and Domestic Allotment Act, are given by Administrator Tolley in his 1936 report. In presenting the data, attention is directed to the fact that the Act was passed at too late a date to allow many farmers to participate, and too late to permit adequate farm planning. The drouth of 1936 also affected the program. The following paragraph is summarized from the report:

More than 283,000,000 acres, or 67% of the crop land in the United States, was covered by the program. In the soil-building and conservation program, legumes were sown alone or in mixtures on 33,578,157 acres; pasture was established on 1,704,198 acres; green manure crops were grown on 7,597,729 acres; forest trees were planted on 22,052 acres; mechanical erosion controls were carried out on 5,027,380 acres; limestone, phosphate, and other chemical fertilizers were used on 3,220,251 acres; orchard improvements were made on 37,046 acres; and miscellaneous practices were applied on 1,825,805 acres. In all, soil-building and conserving practices were put into effect on 53,012,618 acres.

The above are interesting data as giving a picture of the scope of the program and the acreages involved. There is no certain way of determining from these data, however, the extent to which the tabulated results represent departures from and improvements in the usual practice of the country as a whole. The use of diverted acreage for these purposes implies a change to the amount of the diverted acreage. However, since all farms were not in the program, the possible opposing shifts of non-cooperators are unaccounted for. The fact, as stated in former Administrator Davis' report, that existing plantings of meadow crops were included in contract retirements also obscures the total accomplishment. In measuring the success of the program in promoting soil conservation in the country as a whole, it is necessary, therefore, to consult other data.

The best index of accomplishment in a soil-building and soil-conserving program should be the changes in acreages of grasses, annual and perennial legumes, green manure crops, etc., and in lime and fertilizer sales. The most convenient data for indicating crop changes are those collected by the U. S. Dept. of Agriculture. Unless otherwise indicated, data from this source are the basis for the following summaries.

Unfortunately, these data do not show all that may have been accomplished by the A.A.A. program. For example, there are no data available on pasture acreages, except those from the census, and these are useless for the need at hand. Neither are there data on grasses, other than timothy, or on green manure crop acreages. In addition, the crop data are not sufficiently refined and are too much affected by

drouth and insect damage to give a fair picture of original sowings and hence of the complete operations of the program itself. Recognizing these deficiencies, it is felt, however, that trends may be shown and some measure of accomplishment may be arrived at even though not complete in all phases. Granting this, there may be some question as to how much credit should be given to any one agency for such changes as may be noted. The state agricultural experiment stations, the state extension services, and agencies other than the A.A.A. in the U. S. Dept. of Agriculture, all have been and are urging the various measures which the data should reflect. It seems fair to assume, however, that any significant modifications in line with the active recommendations of the A.A.A. can be attributed properly in part to that agency.

Soil conservation features have been given some emphasis during the entire A.A.A. program, so that it seems proper to consider the entire period of the program in a survey of its accomplishments. Emphasizing limitations, a survey of certain key crops follows.

Alfalfa is a basic crop in any extensive soil-building undertaking. The alfalfa acreage during recent years has shown a steady year-to-year increase, except for slight drops in 1934 and 1936. The increases during the years of A.A.A. activity have been greater than in any similar period. These occurred in spite of drouth and grasshopper damage, which undoubtedly caused the loss of some young alfalfa sowings as was true of similar crops. The national annual harvested area during the period 1928-32 averaged 11,720,000 acres. In 1937 this was increased to 13,787,000 acres, which, however, because of the 1936 drouth, was 359,000 acres less than the 1936 acreage. State acreage data for 1937, covering the 10 states of Ohio, Indiana, Illinois, Michigan, Wisconsin, Minnesota, Iowa, Missouri, Kentucky, and Tennessee, showed a combined increase of 2,885,000 acres over the 1928-32 average. This was greater than the total national increase, being balanced by a decrease in the irrigated West. Because the increase in the alfalfa acreage was substantially above that for any similar period, and this in spite of the drouth, it seems reasonable to attribute at least the accelerated increase to the A.A.A. program.

The acreage of sweet clover harvested as hay shows some increase, although nothing approaching that of alfalfa. Interestingly enough, the acreage of sweet clover has tended to remain more or less stationary or to decline in those states where the principal increase in alfalfa has occurred. It has shown a substantial increase in Wisconsin, Minnesota, and North Dakota. In these three states the combined annual average area for the period 1928-32 was 410,000 acres. In 1936 the total was 767,000 acres. National totals for comparison were 866,000 and 1,100,000 acres, respectively, showing a decline elsewhere than in these states. Considering the fact that the sweet clover acreage has shown no marked changes since 1929 other than a slight gradual decline up to 1935, it again seems reasonable to attribute the increase which has occurred during the latter period of A.A.A. activity to that stimulus. In the states where the increase has occurred, it is significant.

The acreage of lespedeza cut for hay also has shown a marked

increase during the period of A.A.A. activity. There was a regular increase each year up to 1936 when there was a sharp reduction, with restoration to the previous top again in 1937. The acreages for the individual years beginning in 1932 and ending in 1937 were 1,115,000, 1,701,000, 1,578,000, and 2,036,000, respectively. The widely grown lespedezas are annuals, and the acreage reduction in 1936 reflected the severe drouth of that year. The Division of Forage Crops and Diseases of the Bureau of Plant Industry estimates that 25,000,000 acres of lespedeza are used for pasture. A number of agencies have claimed credit for the increase in lespedeza production, including the editor of a widely circulated farm journal. There would seem, however, giving everyone his due, to be glory enough for all, and reason to believe that the A.A.A. program should receive a substantial part of it.

Data on clover acreages are the most unsatisfactory of any from which to draw conclusions as to A.A.A. contributions. Because a considerable acreage of clover is grown with timothy, the Crop Reporting Service groups all clover and timothy together. With a decreasing horse population there has been a downward trend in the acreage reported under clover and timothy since 1924, when the total stood at 34,038,000 acres. This reached a low of 20,146,000 acres in 1934 and built back to 22,034,000 acres in 1936. This would suggest a check in the downward trend and some restoration. Any gains, however, were entirely lost as a result of the 1936 drouth with attendant loss of plantings, the 1937 acreage setting a new low of 19,481,000 acres.

The influence of drouth losses on the clover and timothy acreage is shown by the record of a few typical states. Combining the acreages for Ohio, Illinois, and Iowa, where trends were the same, the 1928-32 combined average was 5,985,000 acres. In 1935, following the 1934 drouth, there were 4,061,000 acres. In 1936, following a more favorable season in 1935, there were 5,038,000 acres. Following the drouth of 1936, this was reduced to 3,408,000 acres, which, with the decrease in the national total from 22,010,000 acres to 19,674,000 acres, shows a trend similar to that following 1934.

The drouth of 1936, following a series of bad years, not only affected the amount of current sowings and their survival, but also seriously reduced the seed crop. As a result, seed prices were high for 1937 sowings, particularly for red clover seed. A survey made by the Division of Hay, Feed, and Seed of the Bureau of Agricultural Economics shows that in the section of the retail trade covered by the survey, sale volumes of red clover seed were essentially the same for the years 1934, 1935, and 1936. Prices for these years averaged \$14.75, \$23.65, and \$20.90 per hundred, respectively. In 1937, with an average price of \$38.25 per hundred, the sale volume was only 72.5% of the average volume of the preceding three years. Moreover, the smaller amount of seed available for sale also contributed to reducing sales volume and presumably sowings. Actual data on sowings are not available, and it is necessary to wait for the 1938 acreage data to determine the real total effect.

The foregoing survey of clover and timothy acreages, and of factors influencing trends, indicates how nearly impossible it is to determine the true effects of the A.A.A. program on the basis of the end results



for these crops. There is some suggestion of a positive effect indicated by the increased 1936 acreage following improved conditions in 1935. The data do emphasize, however, the generally unfavorable seasonal sequence under which the A.A.A. program has been operating, and suggest that better results may be expected under different circumstances.

Of the annual legumes, soybeans have made the most phenomenal increase. In 1937 the total area in soybeans grown for hay and seed was 5,996,000 acres, as compared with an average of 3,024,000 acres for the period 1928-32. The 1937 acreage shows an increase of 613,000 acres over the 1936 acreage. Of the total 1937 crop, 3,659,000 acres were cut for hay, as compared with 3,251,000 acres so harvested in 1936, and 2,149,000 as an annual average during the 5 years, 1928-32. There has been an increase in the use of soybeans as hay, which has been encouraged by the A.A.A. The need for an annual legume forage because of perennial legume seedings lost by drouth, and the remarkable drouth resistance of soybeans during 1934 and 1936, have played their part in promoting increased soybean forage plantings. Granting this, it would seem that the A.A.A. should receive its share of credit for the increase.

Under the A.A.A. program, the acreage of cowpeas has nearly doubled, building up from an annual average of 2,301,000 acres for the 5 years, 1928-32, to 3,624,000 acres in 1937. The acreage cut for hay during the same period increased from 1,502,000 acres to 2,237,000 acres. This increase seems rather definitely tied up with the A.A.A.

The A.A.A. has also operated effectively in promoting crop improvement, as shown in the present situation relative to red clover seed of foreign origin. Following the drouth of 1936 with its attendant serious reduction in the seed supply of adapted domestic strains of red clover, there were heavy importations from foreign sources. Experimental data show that these foreign strains are not adapted in many parts of this country. Based on these data and on farm experience, the A.A.A. placed a regulation in effect providing that soil-building payments could be made for clover plantings only when adapted seed was sown, and defining adapted seed as that of domestic or Canadian origin. This ruling probably did more than any other step ever taken to impress on farmers the meaning of adaptation and its importance. Its effects are likewise evident in the much reduced scale of importation during the current importing year in spite of continued shortage in the clover seed supply. One prominent European seed merchant, relying on the short supply in this country, set up special offices in Chicago to handle his import business. Demand was so limited that he closed out and left early in the season. Those interested in clover improvement in this country feel that this move, by preventing excessive dilution of domestic stocks with unadapted foreign strains, in the end will be of marked benefit, even though it may reduce current sowings and present total acreage.

The use of agricultural lime and of fertilizer materials should be a direct reflection of success in a soil-building program. The National Lime Association estimates the use of ground limestone and other lime

materials at 3,736,367 tons in 1929, 3,498,296 tons in 1930, 2,548,941 tons in 1931, 1,839,715 tons in 1932, 1,627,057 tons in 1933, 2,433,841 tons in 1934, 3,291,789 tons in 1935, 6,305,426 tons in 1936, and somewhere between 7 and 8 million tons in 1937. In 1936 the total exceeded 4,000,000 tons for the first time in the history of the industry. This remarkable increase in the use of agricultural lime, centering as it does on the period of the A.A.A. soil-building program, can hardly be attributed to any other factor than that activity. This is one of the most significant measures of accomplishment by the A.A.A.

Fertilizer use likewise shows a strong upward trend during the period from 1933 to 1937. The National Fertilizer Association reports that from a low of 4,335,607 tons in 1932, their record shows a consumption of 4,871,271 tons in 1933, 5,547,520 tons in 1934, 6,220,831 tons in 1935, and 6,820,193 tons in 1936. According to the *Fertilizer Review* of September-October, 1937, the 1937 consumption will probably total about 8,250,000 tons.

The increase in tonnage has been accompanied by an increase of the average plant nutrient content in the fertilizers used in many parts of the country, which adds further significance to the figures given. A summary of fertilizer consumption in the United States, issued by the National Fertilizer Association in August 1937, shows that there has been an increase in the weighted average nutrient content of mixed fertilizers consumed in the country as a whole from a low of 13.9% in 1920 to 18.2% in 1936. This increase has varied for different parts of the country, being greatest for the Northeast and West and least in the South. In 1934 the average nutrient content for all fertilizers used in the South was 16.77% compared with 23.09% for New England, 20.87% for the Midwest, and 20.78% for the Far West.

In this same report is a highly significant statement on the relationship of agricultural purchasing power to fertilizer use which is worth quotation. It is as follows:

"Over a long period of time the total amount of fertilizer used will depend largely on the plant-food deficiencies in soils and the technological developments making possible the furnishing of these plant foods through the application of chemical fertilizers. Year-to-year changes in fertilizer tonnage, however, are determined primarily by economic factors as distinguished from agronomic or scientific factors. Whether the volume of fertilizer used this year is larger or smaller than last year's tonnage does not depend to any appreciable extent on changes in plant food deficiencies in the soil or on industry's ability to manufacture fertilizers to supply these deficiencies. It depends, rather, on changes in the financial ability of the farmer to buy fertilizer. If prices of farm products are higher than a year ago, if crops are good, and if fertilizer prices are regarded as reasonable, it is quite likely that tonnage will be larger.

"It follows that farm income is the best available single indicator of the demand for fertilizer and of the farmer's ability to buy it."

This statement, based on an analysis of fertilizer sales and farm income in various parts of the country, makes clear one reason why the A.A.A. program should be credited with a substantial rôle in increased fertilizer sales. It also emphasizes the fact that the advancement of all sound agronomic practice is intimately associated with

economic prosperity and stability. Sound agronomy is dependent on sound economics, just as sound economics is dependent on sound agronomy. The two cannot be separated.

In addition to the above-noted direct contributions to agronomic betterment arising from the A.A.A., there are others more indirect, yet probably in the end equally or even more significant. As a result of the A.A.A. program, every important agricultural county in the United States now has a county agent. The farm people of each county have come to know and to rely upon their agent and to use his services as never before. The number of his contacts and his effectiveness have been immeasurably increased because of the program. This must in the end have a profound effect upon agronomic improvements.

Another most significant development is the County Agricultural Conservation Association with its county-planning committee. This committee in each county is charged with administering the program and with working out through community committees a balanced soil-building and cropping program for the county, which in turn must be based on a soundly developed plan for each farm. In some states substantial progress already has been made in farm planning and productivity surveys, which ultimately are certain to be strongly influential in building a sound agriculture. These county committees should become increasingly important in the agricultural set-up in each state. They should become a most effective link in the chain of agronomic improvement.

Other examples of the effects of A.A.A. impacts on agronomic betterment doubtless could be pointed out. Enough has been indicated through the foregoing somewhat superficial survey to show, however, that the A.A.A. has contributed, and is contributing, in a very substantial way to advancements in soil conservation and crop practice. It is without question a most potent force for implementing soil and crop science. It adds a new element to the previously existing set-up of the state experiment stations, the extension services, and the research bureaus of the U. S. Dept. of Agriculture. Most of us have failed to realize the real necessity for this new element. We have prided ourselves that agronomy is so necessary and so universal that we and our work are removed from the fields of controversy that rage round all economic problems. In reality these notions have been "delusions of grandeur." Sound agronomy is dependent on and cannot be separated from sound, stabilized economics. Combining the two, the A.A.A. program carries a challenge we cannot avoid.

## INTEGRATING RESEARCH AND EXTENSION IN AGRONOMY<sup>1</sup>

R. D. LEWIS<sup>2</sup>

IN EVERY field of scientific endeavor epoch-making discoveries and rapid accumulations of knowledge have given rise to tremendous problems of fitting the segments and elements into unified and usable systems of action. A layman's casual inspection of the proceedings of various societies and organizations indicates that the topic of "integrating" must truly be a perennial that often buds but seldom discloses the wonders of the blossom! Nor would I lead you to anticipate herein any striking floral display of integration of research and extension in agronomy.

To some the integrating of research and extension in agronomy may be evident both as to desirability and as to methods of accomplishment. Yet any discussion of integration may easily become a series of trite, speculative, vaguely general phrases, and be neither factual nor quantitative. At the start may I note that although this discussion is limited to integration within the field of agronomy, I am quite aware of the tremendous responsibilities that confront research and particularly extension in the correlation of knowledge and activities from all fields that affect the farm family, its home, and its enterprises. Would we not be presumptuous to assume that we are qualified to solve these larger problems, unless we may first effect a greater degree of integration within our own field?

Pasteur gave us a simple but forceful expression of the significance of integrating research and extension when he wrote, "What really leads us forward is a few scientific discoveries and their applications." We are all familiar with the functions of the researcher in agronomy in making discoveries, organizing knowledge, and creating materials, but are we aware of the functions of the extension agronomist? The extension agronomist is the interpreter, the teacher, the correlator of those facts and processes that seemingly may be incorporated into scientific systems of soil management and crop production. His work is going through significant transitions. Formerly the extension agronomist was largely concerned with getting to more farmers the information and practices that were already in use by a few of the leading farmers, who may or may not have acquired the practices as a result of formal agronomic research. This type of extension will and should continue. But with the rapid development of knowledge and creation of new materials, the extension agronomist must concern himself with methods of transmitting these results of research quickly, effectively, and properly balanced for fitting into the agricultural

<sup>1</sup>Contribution from the Department of Agronomy, Ohio State University, Columbus, Ohio, and the Bureau of Plant Industry, U. S. Dept. of Agriculture. Also presented as part of the general program of the annual meeting of the Society at Chicago, Illinois, December 2, 1937.

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programs of many people. Extension is simply a method of teaching, a tried and proved method that had effectively reached hundreds of thousands of rural adults and youths before formal educators even recognized that such teaching was in existence!

To facilitate progress in this discussion, I make certain assumptions that to me seem self-evident. In the first place, research and extension in agronomy have, in general, a common objective—the improvement of rural life through the discovery, organization, and correlation of our knowledge of the physical, chemical, and biological processes in soils and crops into scientific systems of soil management and crop production. Secondly, the granting of public funds to us for the advancement of knowledge and the creation of materials raises responsibilities for incorporation of the knowledge and materials into programs of action and living. More and more, research as well as extension is concerned with the effects of science and its applications upon the individual and his society.

In the third place, the transmitter of science—specifically, the extension agronomist—must realize the probability that action will be taken upon recommendations he makes. It was only a few years ago when he often wondered if anyone would accept those recommendations—now, he must constantly think of the results of large groups accepting them. These three basic considerations leave us no alternative—we must give more thought to the integrating of research and extension.

May I emphatically dismiss any interpretation of the foregoing remarks that might seem to minimize the fundamental values of pure or abstract research. From such springs of knowledge come elements that will eventually be incorporated into highly significant practical developments. As a witness to this I cite the 30 to 50% of the acreage of the Corn Belt that will be planted with corn hybrids in 1938—the direct outgrowth of pure research in the early 1900's, which in turn was based on the researches of Mendel in the 1860's.

If we grant that there should be more “integrating” of research and extension in agronomy, we may logically inquire, “Why don't we have more of it?” and “What situations tend to hinder integration?” May I catalogue a few of these situations? My list concerns mostly the human elements. Many of the hindrances are due to mutual lack of knowledge and appreciation on the part of research and extension workers (3)<sup>3</sup>.

We often note the reluctance of certain research workers to assume interest or accept responsibility beyond the scientific discovery. The process of discovery seems to give far more satisfaction than the attainment of use. The attitude which says, “I've found it! That's enough for me!” reminds one of the college student returning from a date late at night only to be questioned by his roommate: “Come, tell me about it?” “Well, I called for her in a taxi, took her to dinner, and then to a dance, and home again in a taxi.” “Did you kiss her good-night,” pried the roommate. “Why, no,” said the future scientist, “I had done enough for her for one evening.”

<sup>3</sup>Figures in parenthesis refer to “Literature Cited,” p. 187.

While modesty may result in reluctance to assume responsibilities beyond the discoveries, both research and extension would be strengthened if more energy were applied to interpreting the scientific findings to the extension workers. Some of this modesty of the researcher in his relations with the extension agronomists may at times be due to lack of knowledge and appreciation of extension as a method of teaching and a means of getting research results before those who may use them. Some research agronomists of high ability isolate themselves too much. This isolation sometimes leads to inaccurate determinations of the nature of specific soil or crop problems and to the neglect of relationships with other problems.

Now the extension agronomist often works under severe handicaps that hinder the process of integrating research and extension. Frequently, he is not well enough grounded in knowledge, scientific discipline, and in the use of scientific methods. Because of these situations, he may tend to analyze incorrectly cause-effect relationships which might be readily interpreted by applying simple basic principles of soil or crop sciences. He often tends to accept, as fact, observations not based on measurements or thorough examinations of causes.

But, we must realize that every extension agronomist has so many immediate and expedient activities thrust upon him that it generally becomes impossible for him to drive toward a clear-cut objective. He is primarily a man of action, who has little time for reflection. If he is so fortunate as to possess the habit of reflection and at the same time to be a man of action, his work will be outstanding.

As both research and extension workers in agronomy tend to be distinctly human, individuals in both groups are subject to certain common hindrances toward integration of their efforts. Unfortunately, we are at times prone to take up the cudgels against another worker and his ideas rather than to push forward toward the solution of the common problem. Yes, of course, we make progress by "showing up" another agronomist, but at times that progress is needlessly obscured by the smoke of the battle!

Both research and extension workers should have a greater awareness of what the scientific method in action really involves. Our thoughts along this line were greatly stimulated a few years ago by a careful exposition of the elements involved in the "engineering approach". At the conclusion of the exposition someone ventured to inquire of the engineer leading the discussion, "Is not the 'engineering approach' you describe the same in procedure and spirit as what is commonly termed the scientific method—analysis, formation of hypotheses, and testing?" Our engineering friend replied, "One more element must be added to the scientific method for it to become the engineering approach—there must be action. The engineer does something about it." And without quibbling over terms, we in agronomy may well be more active in integrating research and extension.

Both research and extension workers in their enthusiasm for their own findings and projects often neglect to correlate their activities and the applications of their findings and teachings with others in the

same or related fields. Consequently, our work is often needlessly duplicated or at least not properly integrated into a usable and balanced system.

I have often been disturbed by those hasty appraisals that set off individuals as being of the "research" type or of the "extension" type. Too often such appraisals imply that since a given individual is not of the research type, he can be automatically classified as a suitable extension worker. Now, I am fully aware that agronomists can be divided into types—some of us are abstract researchers, or prefer a cloistered life, or just do not like to work intimately with other people in interpreting our findings. But I do plead that in the fundamental spirit of scientific approach to problems, research and extension agronomists shall be alike. A certain man had identical twin sons. He determined to test out the much-disputed Harvard versus Yale traditions and educational systems, so he sent one of the twins to Harvard, the other to Yale. At the completion of their college careers, the father observed to a friend, "John came back from Harvard, a gentleman—and Henry came back from Yale, but still I couldn't tell them apart". And likewise there should be a common bond of spirit that identifies all workers in our field primarily as agronomists, whether or not they happen to be in research or in resident or extension teaching.

The very nature of their respective public services often results in extension over-shadowing research, but the remedy for this lies in the complete recognition of the fundamental relationships between the two fields (2). Planned integration of research and extension in agronomy will bring to the public greater awareness of the basic source of extension teachings and materials—research.

Many significant illustrations of the integrating of research and extension in agronomy are to be found today. Such cases are multiplying. I cite three of them which involve different basic situations. I shall confine these illustrations to projects in Ohio, simply because I know something of the underlying conditions and philosophies.

The Ohio research-extension program for the development and utilization of adapted corn hybrids is an integrated program, founded on the direct usage of ideas and materials created by research. The objectives and the basis for this program were laid in 1932-33 in numerous planning conferences of the research and extension workers in corn improvement. In 1937 this planned program had been developed to the point where 260 growers produced commercial supplies of seed of adapted hybrids and a group of 320 apprentices gained experience with  $\frac{1}{8}$  or  $\frac{1}{4}$  acre crossing plats. By 1937 seed production had been initiated in each of the 88 counties of Ohio. Practically all of the producers are graduates in 1933 or later of that portion of the integrated program which provides education and training for apprentice producers and widespread trials of promising new hybrids.

In developing this program certain fundamentals have guided the cooperating research and extension workers. The ultimate objective has always been the making available of reliable seed of adapted hybrids at a price consistent with the best interests of both producer and user. The research and extension institutions accepted responsi-



bilities to see that effective use be made of created materials. A small beginning was followed by a steady growth toward wide participation. This participation was initiated on an experimental and educational basis through the apprentice system. The prospective small-scale producer of interest and ability has been given the same initial opportunity as the larger producer. Close contact with the growers has been maintained through informational news letters, circulars, special training schools, individual visits, and a formal inspection and certification system. For instance, the number of mimeographed news letters and circulars on instructions and procedures exceeded 60 during 1937.

Thus, a trained and cooperative group of producers has been developed for the production first of commercial hybrids and then of foundation seed stocks. In the earlier stages of the program, the co-operating research and extension services accepted the responsibility for the production and distribution of foundation seed stocks of single crosses. In 1937, after a trained personnel had been developed through the integrated program, we assisted a cooperative group, representing a large majority of the producers, to initiate a seed stocks producing organization which will continue to assure reliable foundation seed stocks to small as well as large producers and make possible the continued correlation of production, distribution, and use of such seed stocks (1).

In this cooperative hybrid corn program there has been a direct and unbroken current of ideas and materials from research through extension to seed producer and seed user. The research program has been influenced by the interrelationship; all significant steps in the extension phases of the program have been taken in accordance with the underlying research information. Policies and problems have been solved by cooperative thought and action and those closely inter-related have at no time been separated into distinct research and extension functions. Undoubtedly a major factor in this orderly development was that the participating research and extension workers were well trained in the fundamentals of modern plant breeding.

Incidentally may I note here that integration in our hybrid corn program has extended beyond our state, for there has been no reluctance on the part of the research and extension workers in corn improvement to make effective use of inbred lines and hybrids developed elsewhere. The sole determining factors have been performance and the availability of reliable seed stocks.

Another type of integrated program, which I call the interplay or reversible exchange type of integration, is illustrated by the research-extension projects on methods of seeding meadows in Ohio. Type, extent, and regularity of meadows are the outstanding constructive factors in the conservation and improvement of the productive capacities of Ohio soils. Why then do we not have more uniformly good meadows? The difficulties of obtaining good stands of forages seem to be the bottle neck of the problem. Any program for increasing the proportion of land in soil-building sod crops must first of all attack the problems of obtaining seedings.

From research and extension work in this field agronomists began to develop in 1932 tentative outlines of the factors involved in obtaining successful stands of legumes and grasses. Existing information was fitted into appropriate places within these outlines, and the research men directed further experiments toward filling in the weak points in our knowledge of seeding methods. At the same time the extension agronomists, aided by a series of lantern slides provided by the investigators, conducted further discussion groups with farmers. From each of these meetings came suggestions as to investigations or methods of research and extension approach to the problems. Naturally, both research and extension approaches were modified by these interchanges.

As a result of these interchanges of experiments and experiences, there was finally developed in 1936 a chronological outline of the more important causes for failures to obtain stands of meadow crops. Methods of counteracting these causes were organized into workable, practical, and successful systems of seeding meadows. Causes for failure, seeding and management technics designed to counteract these causes, and the organized systems of seeding methods have now been collected into a bulletin recently published by the Ohio Experiment Station on "Better Methods of Seeding Meadows" (6). Curiously enough portions of this bulletin, summarizing the methods of obtaining better seedings under the three most frequent situations obtaining in Ohio, were incorporated into mimeographed extension circulars and presented by discussion and lantern slides to numerous farm groups well ahead of formal publication of the bulletin.

It is evident to those of us who have participated in this reversible action type of integration that research and extension have profited both as to fundamental knowledge and as to methods of organization and presentation.

The two preceding illustrations of the integrating of research and extension in agronomy have originated in specialized activities with a single crop, corn, and with a group of meadow crops. Such activities, of course, represent only segments of a complete and balanced program in agronomy. However, there is small likelihood of our approaching either completeness or balance unless these segments be so constructed that they can be fitted into their proper places in a synthetic approach to the larger problems of agriculture. Inferior workmanship or quality of materials in the smaller segments will but weaken or mar the structure we hope to build.

And we shall not be permitted to play forever and alone with the individual blocks or segments. While there may have been a tendency in the past to advance improved practices more or less independently, it would seem that the progress made in agronomic knowledge, materials, and approaches should now justify more attempts by research and extension agronomists to weave together significant systems of soil and crop management. Nor can integration be confined within agronomy. In both research and extension we note that correlation and integration are cutting across subject matter lines whenever the attainment of desirable objectives can be facilitated by

bringing the thought and action of various interest groups to the attack of the underlying problems.

In common with agronomists of other states, we in Ohio have attempted to develop a systematic approach to the use of land on individual farms. We have brought together information from researches as a basis for analyzing what the net effect of a given system of soil and crop management may be on the productive ability of soil.

We have dared to suggest and use simple mathematical expressions by which the effects of individual crops and soil practices upon soil productivity might be approximated—both to facilitate analysis of existing systems and the synthesis of more desirable systems. As this method of integrating the segments of soil and crop management into a combined and simple expression has been fully presented elsewhere (5) and discussed by a former president of this Society (4), I desire to point out here something of how the system came into use and how it is effecting a greater degree of integration within agronomic activities in our own state.

In 1932 the need for indexes that would evaluate, at least approximately, the effects of individual crops and of various soil practices was expressed in a conference of the research and extension agronomists. At the Experiment Station studies had been progressing on changes taking place in the soils over periods of 35 to 40 years. In 1933, research-extension agronomists suggested tentative productivity indexes for certain crops as a possible basis for payments on contracted areas under the Agricultural Adjustment Administration. In 1934, these tentative indexes were found to be highly valuable in simplifying the appraisals of corn lands. A year later, the research-extension agronomists were confronted with the problem of analyzing the effects of existing generalized cropping systems on the productive abilities of Ohio soils and suggesting regional changes that should be made to conserve and improve these productive abilities.

Accepting the challenge, research and extension agronomists examined again the foundations for the productivity index system of analysis and synthesis. We recognized imperfections and discovered many places where fundamental information was lacking or meagre. The indexes were refined and used as a basis for the studies on regional agricultural adjustments in Ohio. In 1935 and 1936, the same indexes, appropriately modified for such factors as erosion, use of manure and fertilizer, etc., provided the basic method of analyzing the generalized soil and cropping system of each county in the state. During the past two years, thousands of Ohio farmers have examined practices on individual farms and have started to reorganize their individual soil and cropping systems. On these individual farms the "productivity balance" is obtained by weighing each crop and soil practice according to its probable effect on soil productivity. By setting the favorable factors collectively against the unfavorable ones, a net result called the "productivity balance", is derived. This balance is a collective expression that includes the chemical, physical, and biological resources of the soil concerned. This method of approach has enabled individual farmers to grasp the nature and effect of the cropping

systems and soil management practices that they have been following and they have thereby discovered the weak points.

This is only one of a possible series of illustrations of integration of segments into a workable system that have been developed by correlation and integration of research and extension. Needless to say, such an approach has had a profound effect upon research programs in agronomy and in related fields. The agricultural economists have demonstrated by field surveys of actual farms during 1936 and 1937 the validity of the productivity index method of approach and have found a high correlation between productivity balances and farm income. In the field of extension agronomy, the application of individual improved practices assumes new importance as we are enabled to see more clearly how specific practices fit into the system with which the farmer deals.

So much for the past! Let us look briefly at the future.

Every agronomist could cite cases where present and future research activities raise the necessity for a planned integration of research and extension. We will probably trend toward accepting greater responsibilities for originating and directing, at least during the development stages, successful method of utilizing the out-turns of research. May I cite two examples of the developing need for integrating research and extension?

The first example concerns the general problem of adaptation of seeds of farm crops. "By their performance you shall know them" is still a long way from wide realization in farm practices with seeds. There is too little appreciation of the significance of the fundamental factor of heredity in determining adaptation and performance. If you are skeptical of such a statement, go among groups of farmers and even examine comparatively recent statements and writings of some agronomists relative to the alleged significance of various ear characters in forecasting yield in corn. And these reactions exist in spite of 30-year-old research by agronomists and several symposia on the subject before this Society! Yes, we have come a long way in the past 25 years in utilizing the out-turns of modern plant breeding methods, but in the general movement of many seeds the trend from a commodity to a speciality basis needs to be encouraged vigorously by agronomists. The problems of "how" this trend can best be encouraged challenge plant breeders and associated agronomists to greater efforts.

Such thoughts were expressed recently in a conversation with a seedsman. His comment was simply, "There's no demand for such seed; if so, we would service it." I wonder. Why, for instance, aren't there wider demands for red clovers and alfalfas of the highest known adaptations? Were we as agronomists to take more responsibility in seeing that these desirable strains really get a chance, would not the best of them come into sufficient prominence to be in active demand? Even the telephone and radio did not come into being as the result of demands! The odds are high against most new developments unless their acceptance and use are sponsored by some group.

The second example is really a specialized phase of the first. In the field of forage and pasture crops, there is at present tremendous plant

breeding activity. These intensive plant breeding attacks will result in superior strains, but many of these efforts will be nullified unless far more attention is directed both in research and extension toward the problems of multiplication, maintenance of identity, distribution, and utilization. With the advent of these new and superior strains, the production of seed of forage and pasture crops must be shifted from incidental farm enterprises to deliberate planned programs. The best thought in research and extension will be required to fit together the elements into sound, sensible programs of increase and distribution. Production and marketing costs will be increased for it will become necessary that identities of strains and lots be maintained through all stages of multiplication and distribution.

In what ways can prospective users of these improved strains be best brought to a realization of the value and economy of using them? How can they make certain the purchase of seed of the specific strain or blend desired? Because these problems of seed production and use will ignore state lines, the integrating process between research and extension will require coordination on regional or zone bases. It would be wise to initiate studies and preliminary plans of the functions research and extension are to play in this developing field. I believe that these problems with forage crops will be much more varied and far more difficult than those faced in the Corn Belt in recent years in the development and use of corn hybrids.

By way of summary, integration of research and extension in agronomy is stimulated by certain observances and practices. Above all, those going into extension in agronomy should be as well trained in the fundamentals of agronomy and contributing sciences as those going into research. To the extension worker the well-established principles of these sciences should be ever ready tools to be used in building projects and analyzing situations.

The interpretation of science challenges the younger agronomists, and the translation of the ideas and materials created by agronomic science into useful systems of soil and crop management offers opportunities for service fully as attractive as does the acquisition of new facts or the creation of new materials.

Integration will be facilitated if there is participation of each group in overlapping activities. The planes of demarcation should not be flat but rather interlocking. The research worker need not become an extension worker, but each will profit by familiarity with some of the problems and methods of the other. Integration is facilitated whenever extension agronomists assist in analyzing and classifying research problems that have been suggested from their activities or relationships. The extension agronomist moves toward the integrated objective when research agronomists suggest ideas and materials that are seemingly ready for extension. Cooperative discussion and planning of investigations and projects activate the integrating processes.

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## THE CORRELATION OF THE EXTENSION AGRONOMY PROGRAM WITH THE RELATED PROGRAMS OF THE SOIL CONSERVATION SERVICE, THE FARM SECURITY ADMINISTRATION, AND THE AGRICULTURAL ADJUSTMENT ADMINISTRATION<sup>1</sup>

T. G. STEWART<sup>2</sup>

IT has been rather easy to correlate programs of the Farm Security Administration, A.A.A., and S.C.S. with the extension programs in Colorado for three reasons. First, we suspect that extension workers or former extension workers have had a great deal to do with writing the new programs. Extension interpretations, viewpoints, and relationships appear quite frequently.

Second, we find former extension workers in many of the administrative positions in S.C.S., A.A.A., and Farm Security. The first state coordinator of the S.C.S. was formerly an extension agronomist in Colorado and the present acting coordinator was formerly a county agent. The 1937 A.A.A., program for the Western Region was largely written by a former extension agronomist with state technical committees acting in an advisory capacity. The executive secretary for the A.A.A. in Colorado was a county agent for 21 years. The State Rehabilitation Supervisor for Farm Security and the Regional Director of Land Purchase in the Dust Bowl for the Bureau of Agricultural Economics were former Colorado county agents.

Third, under the able leadership of our Extension Director there has been in operation for more than a year an Agricultural Clearing Committee composed of the administrative heads of all federal and state agencies having an agricultural program in the state. Early meetings of this Clearing Committee were devoted to an explanation and discussion of the policies and programs of each agency. The function and program of each agency has been printed for the information of the membership. There are frequent changes and interpretations to be discussed, together with other topics provided by program committees at the regular meetings of the Clearing Committee.

It is not at all surprising to find that as men become acquainted they discover that the program of each agency is fully justified, that there is sufficient work to be done to keep all busy, and that it is possible to work together on a coordinated program pointing toward a planned agriculture for the state and an agricultural plan for each farm or ranch.

The Agricultural Conservation Program is a *device* to be used to the maximum extent by all agencies in securing the adoption of desirable extension agronomic practices. Certainly any extension agronomist should welcome the persuasive powers of the blue check to add to the persuasive powers of education in hastening the development

<sup>1</sup>Contribution from the Extension Service, Fort Collins, Colo. Also presented on the Extension Program at the annual meeting of the Society held in Chicago, Ill., December 1 to 3, 1937. Received for publication January 24, 1938.

<sup>2</sup>Extension Soil Conservationist.



of the crops and soils program. The educational field in connection with the development of the A.C.P. remains within the extension service. The A.A.A. has created such a demand for information that we have had difficulty in supplying it. Our county agents have been so loaded with mechanics and details that they have not had time to devote to the intensive educational program when education was needed. We hope that this rough spot will soon be smoothed over.

We appreciate the special basic or research publications coming from Iowa on the Economics of Agricultural Adjustment. In Colorado we are attempting to meet the immediate demand of farmers and ranchmen for information on the practices and requirements of the A.C.P., Farm Security Administration, and S.C.S. program through a group of popular circulars, as follows:

Keep Your Farm Productive:

1. Rotate your Crops on Irrigated Land.
2. Rotate your Crops on Dryland.
3. By Controlling Noxious Weeds.
4. By Controlled Summer Fallow.
5. By Seeding Alfalfa and Clovers.
6. Plant a Permanent Irrigated Pasture

Save Your Soil:

7. By Terracing.
8. How to Run Contour and Grade Lines.
9. Establish Grass on Non-irrigated Land.
10. By Saving the Runoff.
11. Plant Shelterbelts and Windbreaks.

Improve Your Range:

12. Practice Proper Grazing.
13. By Rodent Control.
14. By Reseeding and the Use of Annual Pastures.

We look upon Farm Security as another *device* which can be used to put the extension agronomy program into effect on many farms. Land use studies and rural sociological problems mapped by Farm Security, together with Soil Conservation Service soil reconnaissance surveys, serve to point the way for action programs of all agencies. Farm Security rehabilitation supervisors encourage the purchase of pure seed of standard varieties. They are attempting to finance only an improved soil management program on the farms of their clients. In our greater problem area, the so-called Dust Bowl, there is a tendency to finance with Farm Security money clients only on economic units who are willing to follow a safer plan of farming. Again the persuasive powers of loans from Farm Security may be added to the persuasive powers of education.

The S.C.S. program is largely educational by demonstration, somewhat the same as the extension method of teaching. The Soil Conservation Service offers the persuasive powers of a great amount of service and some material aid to farmers on project or camp areas. The big job of soil conservation still lies outside of the project and camp areas. Is it not the sensible thing to do to combine the S.C.S. and extension programs and move soil conservation to all sections of the state and, if possible, to every farm or ranch in the state?

We have begun moving the soil conservation program into areas away from projects and camps through the cooperative farmer-demonstrator. The county agent picks the demonstrator, S.C.S. technicians map the farm, and the farmer, county agent, Soil Conservation specialist, and S.C.S. technicians plan the conservation program. The farmer carries out the 5-year conservation plan for his farm with the supervision of county agent and other technicians. This cooperative program has provided 74 farm demonstrations in Colorado at locations convenient to many farmers throughout the state. These cooperative farm demonstrations take advantage of the provisions of the A.A.A. and sometimes Farm Security and we believe have a tendency to shift the job of conservation back to the farmer.

Our Agricultural Clearing Committee recognized the need for a zoning law and some kind of a law which would protect a restoration or revegetation and conservation program.

The Clearing Committee, through its legislative committee, favored the passage of the Soil Erosion District law, patterned after the standard act which was favored in some 22 states, with slight modification. The Soil Erosion District law passed the Colorado Legislature without a dissenting vote. We see in this law another device effectively to correlate and coordinate the programs of all agencies into an action program which will become the program for the district.

The Soil Erosion District law will provide local organizations and adds the police powers, if needed, to the persuasive powers of education, A. C. P. payments, and Farm Security loans or grants in carrying out a more effective conservation program—an excellent opportunity, we believe, to expand the extension agronomy program.

Just now we are experimenting with county coordinating committees, patterned after the State Clearing Committee, in the hope that field workers may more effectively cooperate in carrying out action programs in the counties to avoid the appearance of duplication of effort.

The County Coordinating Committee is organized as follows:

County agent, chairman.

R. R. Supervisor of Farm Security Administration.

Representative of the S.C.S. wherever such individual is available.

All members of the county A.C.P. committee.

One farmer member of the Board of County Commissioners, to be designated by the Board of Commissioners.

Chairman of the County Planning Committee.

Representative of the Farm Credit Administration.

One member of the Board of District Supervisors of any soil erosion district which may be organized in the county.

Representative of the Land Utilization Division, Bureau of Agricultural Economics, such as Repurchase Project Manager.

If agencies other than these listed are to be included in these county coordinating committees, such additions will be subject to the approval of the State Agricultural Clearing Committee.

While we do not know how well it will work, we do believe that some such general plan of organization may be used to correlate the

programs in extension agronomy with the related programs of the S. C.S., the Farm Security Administration, and the Agricultural Adjustment Administration. In Colorado we rather like this slogan. "There is no limit to the amount of good which one can do if he does not care who gets the credit."

# INHERITANCE IN A CROSS BETWEEN *AVENA SATIVA* AND *AVENA STERILIS LUDOVICIANA*<sup>1</sup>

G. K. MIDDLETON<sup>2</sup>

THIS is a study of the inheritance of kernel characters and linkage relations in a cross between *Avena sativa* var. Aurora and *A. sterilis Ludoviciana*, a wild form. Characters studied were basal articulation, color of lemma, dorsal and basal pubescence, and strength of awn. Of especial interest was the occurrence in certain families of plants of the *A. fatua* type.

## REVIEW OF LITERATURE

### BASAL ARTICULATION

Unit-factor differences for type of basal articulation have been found in most species crosses in oats, including crosses of *A. fatua* × *A. sativa* (19, 13)<sup>3</sup>, *A. fatua* × *A. byzantina* (14, 12), *A. fatua* × *A. sterilis* (5), and *A. sterilis* × *A. sativa* (5). In a cross of *A. byzantina* var. Coast-black × *A. fatua*, Florell (5) found a two-factor difference, the segregation in F<sub>2</sub> giving 15 non-articulate to 1 articulate. When classified as to species types, the segregation was 12 *byzantina*: 3 *sterilis*: 1 *fatua*.

In a study of inheritance in *A. fatua*, Surface (19) found complete linkage between the wild-type base, or callus, strongly geniculate and twisted awns on both lower and upper kernels, pubescence on the rachilla segment of the second floret, and the ring of hairs around the callus. The inheritance of this "wild-oat complex" as a unit in a cross of *A. fatua* and *A. sativa* was also reported by Love and Craig (13) and by Florell (5). The latter found a complete linkage of these characters in each of seven interspecific crosses with the exception of *A. fatua* by *A. byzantina* var. Fulghum. In this cross slight crossing over occurred, which produced a few wild *sterilis* and also what appeared to be *sativa*-like plants. This led Florell to conclude that this character complex is controlled by two or more closely linked factors.

In addition to studies of inheritance in artificial crosses, a great deal of attention has been given by various workers to the occurrence of fatuoids, or false wild types, in fields of cultivated oats. Natural crossing, gene mutation, and chromosome aberration have each been proposed as the possible origin of these aberrant forms. In a recent paper, Aamodt, Johnston, and Manson (1) compared the segregation of artificial crosses of *A. fatua* and *A. sativa* with segregation of fatuoids found in fields of cultivated oats, and stated that, "Fatuoids, or false wild oats, identical morphologically and genetically with common fatuoids, appeared as normal Mendelian segregates from both natural and artificial crosses." They

<sup>1</sup>The data have been presented by the author in a thesis to the Graduate School of Cornell University in partial fulfillment of the requirements for the degree of doctor of philosophy. The material for this study was furnished by Dr. H. H. Love, Department of Plant Breeding, Cornell University, Ithaca, N. Y., where the original cross was made and the first and part of the succeeding generations were grown. Received for publication December 6, 1937.

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<sup>3</sup>Figures in parenthesis refer to "Literature Cited," p. 207.

concluded that so far as the common type fatuoid is concerned, natural hybridization is the principal way in which they originate. Zade (21) and Tschermak (20) had earlier expressed the view that false wild types were the result of natural crosses. Huskins and Fryer (9), Huskins (10, 11), Jones (12), and Philip (17), on the other hand, from extensive genetic and cytological studies, favor the idea of chromosome aberration. Huskins (11) describes four types of fatuoids which differ in their chromosome number. He states, "In heterozygous fatuoids, which give different segregation ratios, different distinct cytological conditions have been found. The combined cytological and genetical evidence seems clearly to show that fatuoids arise from normal oats, neither by natural crossing between *A. sativa* and *A. fatua* nor by gene mutation, as previous authors have believed, but by chromosome aberration."

Coffman and Taylor (2, 3) report the spontaneous appearance of 0.2% fatuoids in lines of normal Fulghum oats that had been self-pollinated for four generations.

#### COLOR, PUBESCENCE, AND AWNS

Independent segregation of factors for black, grey, and yellow in a ratio of 12: 3: 1 was reported by Surface (19) and by Love and Craig (13). Aamodt, Johnson, and Manson (1) reported a similar segregation of factors for black, grey, and white. These were all crosses of *A. fatua* and *A. sativa*. In a cross of *A. byzantina* var. Burt by *A. sativa* var. Sixty Day, Fraser (6) obtained in  $F_2$  approximately 48 red: 15 yellow: 1 white-kerneled plant. Odland (16) found a single factor difference between black and white in a cross of *A. sativa* var. Early Gothland and *A. sativa orientalis* var. Garton.

Surface (19) found the factor for dorsal or lemma pubescence on the lower kernel closely, but not completely, linked with that for black, and basic to the development of pubescence on the upper kernel. When the basic gene was present, pubescence on the upper kernel segregated independently. Two genes for pubescence, one linked with and one independent of that for black color, were found by Love and Craig (13) and by Philip (17). Love and Craig found a relationship to exist between the yellow color of Sixty Day and the absence of awns and pubescence and the wild base. The yellow oats color inhibited awns and pubescence and oats with yellow kernels exhibited no wild type of base. Nilsson-Ehle (15) found an inhibitor to awning linked with yellow in a study of the inheritance of the weak awn in a cross between an awnless variety and one which had an average of 54% of awns. Love and Fraser (14) and Fraser (6) made a very detailed study of the inheritance of the weak awn in their cross of Sixty Day, an awnless variety, and Burt, a fully awned type. There was nearly complete dominance of the awnless condition in the first generation. The second generation gave awnless, partly awned, and fully awned plants in approximately a 1: 2: 1 ratio. A third generation test showed the fully awned condition to be the recessive. The data indicate that while Sixty Day carries an inhibitor to awning linked with the gene for yellow, no such factor is associated with the yellow gene carried by Burt. It was pointed out that the occurrence of awns in the awnless and partly-awned groups was apparently influenced somewhat by environment. Linkage was found between the Burt type of base, medium long basal hairs, and a fully awned condition. Short basal hairs or no basal hairs were found dominant over those which are medium long.

Philip (17) found the factors for white lemma (the double recessive) inhibited lemma pubescence. Aamodt, Johnson, and Manson (1) found no lemma pubescence on white-kerneled plants but found all black lemmas to carry pubescence,

and stated that it is obviously a case of linkage between genes for black and pubescence, or that the expression of pubescence is inhibited by the factor for white lemma color.

In crosses of *Ruvia* (*A. sterilis*) and three varieties of *A. sativa*, Cotner (4) obtained approximately 15 smooth: 1 pubescent plant, pubescence being brought in by *Ruvia*.

#### MATERIALS USED

The data presented here are from a cross between *A. sativa* var. *Aurora* and *A. sterilis Ludoviciana*. These two forms are referred to as the *sativa* and wild parents, respectively.

The kernel of the wild parent is brown or reddish black in color. Both kernels have strong geniculate, twisted awns, and both are dorsally pubescent, though that on the lower kernel is often the heavier. The base of the lower kernel is expanded into a sucker-like ring or callus which permits the grain to shatter easily. When the lower and upper kernels are separated the rachilla adheres to the upper, as distinct from the condition in *A. fatua* where it separates from the upper. From the callus around the base of the lower kernel, and also from the lower part of the rachilla of the upper, grows a thick ring of basal hairs. The length of these hairs is approximately  $\frac{1}{16}$  inch, and is referred to as short.

The base of the other parent is that of the true *A. sativa*, and is rather compressed. Upon separation of the kernels the rachilla breaks free from the upper. The grain of this variety is yellow. This is a good yellow when grown in the greenhouse, but upon weathering in the field takes on a slight reddish cast. This variety is generally considered to be smooth as regards awns and pubescence, and no dorsal pubescence was ever found. An examination of the parental material as grown both at Ithaca, N. Y., and at Raleigh, N. C., revealed the presence of only an occasional hair, these being about  $\frac{1}{8}$  inch in length. The material grown at Ithaca showed no awns, but of the plants grown at Raleigh four produced one very weak awn each and on one plant 40% of the spikelets bore awns.

#### METHODS OF STUDY

The parents and the first generation hybrids were grown in the greenhouse at Ithaca, N. Y. Subsequent generations were grown in the field, part at Ithaca, N. Y., and part at Raleigh, N. C. Two  $F_1$  families, 437a1 and 437a2, were planted at Ithaca and gave a total of 503  $F_2$  plants. Lines from these two families were used for study in  $F_3$  and later generations. In addition to these two lines, families 437a3, 437a4, and 437b1 were grown at Raleigh, N. C., and increased the total  $F_2$  population to 868 plants.

A number of families were grown for  $F_3$  but due to unfavorable weather conditions most of this material was lost. Twenty-five families were planted another year and in general produced good material for study. In these families as large numbers as possible were secured. In addition to these, a complete  $F_3$  generation was grown from the  $F_2$  material of family 437a2. This was done by planting single 4-foot rows from each  $F_2$  plant. This same procedure was also used in checking all  $F_2$  nonblacks in family 437a1, and for other questionable types of inheritance in  $F_2$  and in certain  $F_3$  families.

#### RESULTS

##### INHERITANCE OF BASAL ARTICULATION

The wild base is distinguished easily by the sucker-like mouth, while that of the *sativa* form is narrow and contracted. The  $F_1$  ap-

peared like the *sativa* form but could be distinguished from it. In later generations the intermediates were separated from the *sativa* types by the breaking of the rachilla; when it broke easily from the upper kernel, the plant was classed as *sativa*, but when it would hang or break with difficulty, it was called intermediate. (See Fig. 1.)

The  $F_2$  gave approximately 1 *sativa*: 2 intermediate: 1 wild, indicating a single gene difference for type of basal articulation. The observed numbers in these three classes were 231: 423: 214, respectively. Due to the difficulty in clearly separating the intermediate and true *sativa* plants in all cases, these two classes have been grouped together in Table 1.

TABLE 1.—Showing the segregation as to type of basal articulation in  $F_2$  in a cross of *A. sativa* var. *Aurora*  $\times$  *A. sterilis* *Ludoviciana*.

Basal articulation	Observed	Expected	D	P. E.	D/P. E.
Cultivated.....	654	651.0			
Wild.....	214	217.0	3.0	8.60	0.35

The breeding behavior in  $F_3$  was in agreement with the results of  $F_2$ , 5 families breeding true for *sativa*, 12 segregating, and 5 breeding true for the wild-type base. A summary of the segregating families shows 287 *sativa*; 483 intermediate: 244 wild plants.

In one  $F_2$  family, and again in certain  $F_4$  families, a few *fatua*-like plants occurred. Because of certain association of characters, however, a discussion of these forms is left until later.

#### INHERITANCE OF COLOR OF KERNEL

In the description of the varieties used it was noted that the color of the *sativa* parent was yellow and that of the wild parent brown or reddish black, which is hereafter referred to as black.

The  $F_1$  was black, while the  $F_2$  segregated for black, red, and yellow in numbers approximating a 12:3:1 ratio. The red sorts were a very light shade of red and in case of weathering, or when a plant was slightly immature when harvested, the correct classification of the reds and yellows was difficult. Samples of seed from different red and yellow varieties were used as standards, but as the shades of color in these did not match the material being studied they were not satisfactory. Finally, standards were set up within one well-matured  $F_3$  family, 437a2-64, by mounting typical seeds of each plant. This family was segregating for red and yellow only. It had previously been noted that in the  $F_2$  material all wild non-blacks were red, and that the confusion arose in separating the red and yellow sorts in the cultivated classes. When the family mentioned above was mounted, it was found that all those in the wild group were red, those in the *sativa* group yellow, and those in the intermediate group intermediate not only for type of base but also for red and yellow color. When the well-matured families previously classified were rechecked on this basis, it was found that two agreed perfectly, while the others agreed with the exception of two or three plants each, and in these cases the



correct classification for basal articulation was as doubtful as was that for color. The  $F_2$  data for the material grown at Ithaca, N. Y., are presented in Table 2.

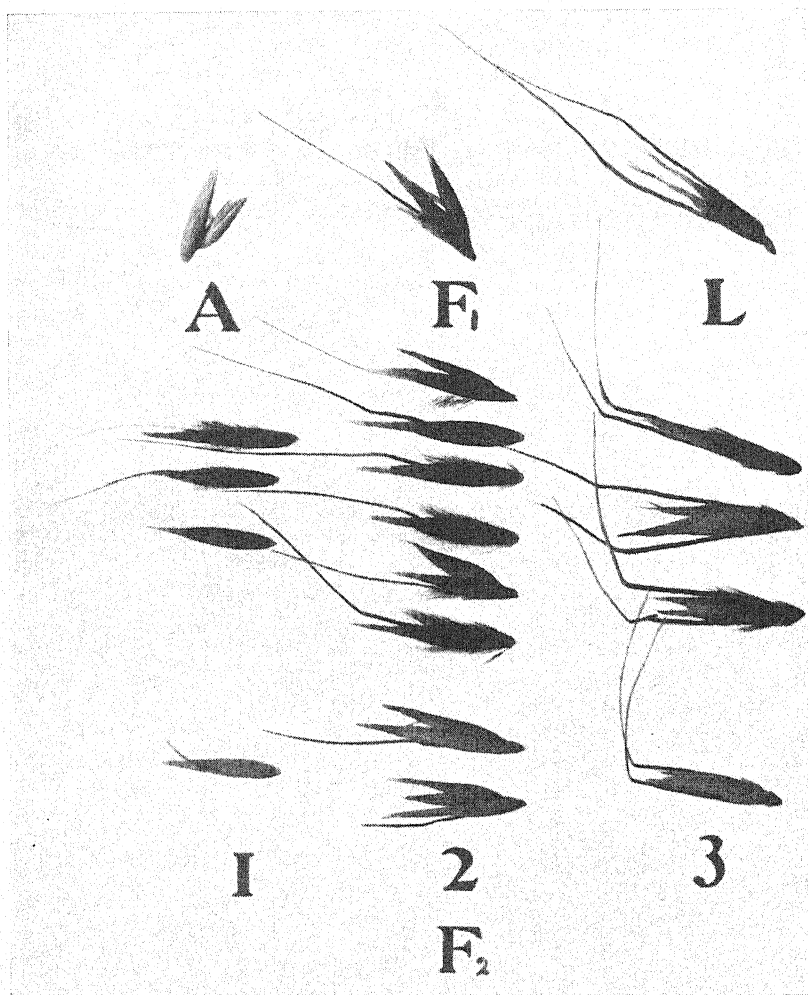


FIG. 1.—*Avena sativa* var. Aurora  $\times$  *A. sterilis* Ludoviciana. A, Aurora;  $F_1$ , the hybrid; and L, Ludoviciana. Balance of figure shows representative  $F_2$  segregates, grouped according to basal articulation and color as follows: 1, *sativa*; 2, intermediate; 3, wild *sterilis*. Ratios 1:2:1 for articulation and 3:1 for black and non-black. Complete color classification shows 12 black:3 red:1 yellow. There was very close linkage between the wild type base, strong geniculate, and twisted awns, complete ring of basal hairs around the callus and red color of kernel, the latter being hypostatic to black. There was also linkage between factors for black color and dorsal pubescence of kernel.

TABLE 2.—Showing the segregation for color of kernel in certain  $F_2$  families, 437a1 and 437a2, in a cross of *A. sativa* var. *Aurora*  $\times$  *A. sterilis* *Ludoviciana*.

Basal articulation	Color of kernel				
	Black	Red	Reddish-Yellow	Yellow	Total
Wild. ....	85	22	—	—	107
Intermediate. ....	206	—	58	—	264
<i>Sativa</i> . ....	103	—	—	29	132
	394	80		29	503

For  $n' = 2$ ,  $P$  is approximately .2.

The material grown at Raleigh, N. C., weathered somewhat and was classified simply as black and non-black. A summation of the entire  $F_2$  data gives 677 black: 191 non-black, with a D/P. E. value of 3.02.

The interesting thing about the data in Table 2 is the linkage relation between genes for red color and the wild base. Whether there is a similar linkage between genes for yellow and the *sativa* base, or whether yellow is entirely independent and is simply hypostatic to red, can not be determined from the data.

The data from those  $F_3$  families in which definite classification of the non-black plants could be made are in close agreement with that shown in Table 2, with a few exceptions.

In family 437a1-95 there occurred one break in the linkage between the genes for red color and the wild base. One plant which appeared as a true yellow in the intermediate group bred true for color in  $F_4$ , giving 21 cultivated: 5 wild, all of which were yellow.

There were a few cases in which red or yellow  $F_2$  plants threw one or two black plants in  $F_3$ . Family 437 a2-51 produced two black plants and family 437a2-58 produced one, while all other plants in these families were non-black in color. Each of these black-kerneled types were planted and their behavior noted in  $F_4$ . One of these produced only dwarf plants which did not head; the second produced 6 black to 1 red-kerneled plant, and a number of dwarf plants; while the third produced 14 black: 4 red-kerneled plants.

In addition to these regular  $F_3$  families, a single 4-foot row was planted from each non-black plant in certain  $F_2$  families. Six out of 88 of these threw one black plant each, while otherwise they appeared to be normal for red or yellow. It is possible that natural crossing was responsible for some of these black-kerneled plants. Stanton and Coffman (18), Griffiee and Hayes (8), and Garber and Quisenberry (7) have reported on the amount of natural crossing found in oats in Colorado, Minnesota, and West Virginia, respectively. This has been found to vary from only 1 natural cross in 7,742 plants in varieties of *A. sativa* at Morgantown, W. Va., to as high as 1.4% in one variety at University Farm, St. Paul, Minn. In breeding investigations with oats at the Cornell Agricultural Experiment Station, very little evidence of natural crossing has been observed.

In addition to this possibility of natural crossing, it is probably significant that in two of the three plants tested all or part of the progeny were dwarfs. This shows that at least part of these plants were abnormal and suggests the possibility of some chromosome aberration.

# INHERITANCE OF PUBESCENCE AND AWNING

*Dorsal pubescence.*—Both kernels of the wild parent are covered with heavy dorsal hairs, though the upper kernel is usually less pubescent than the lower. The *sativa* parent is always smooth. The F<sub>1</sub> was black and pubescent on the lower kernel and had an occasional hair on the upper kernel.

In  $F_2$  all black-kerneled plants showed dorsal pubescence on the lower kernel and all non-blacks were smooth, showing complete linkage between genes for black and pubescence. There were no exceptions to this in the third generation. While all black-kerneled plants were pubescent on the lower kernel, only part of them showed pubescence on the upper kernel in this generation. When this character is studied in connection with basal articulation, it appears that the latter is in some way modifying the appearance of pubescence on the upper kernel (Table 3).

TABLE 3.—Showing the linkage of genes for dorsal pubescence and black color and the modification of the former in certain basal articulation groups in a cross of *A. sativa* var. *Aurora* × *A. sterilis* *Ludoviciana*.

Wild			Intermediate			<i>Sativa</i>		
Black	Non-black		Black	Non-black		Black	Non-black	
Number of Pubescent Kernels in the Spikelet								
2	1	0	2	1	0	2	1	0
85	—	22	178	28	57	33	70	30

It is to be observed in Table 3 that of 98 black-kerneled plants which showed pubescence on only one kernel, 70 were in the *sativa* group. Seventy-three of these, 28 from the intermediate group and 45 from the *sativa* group, were checked further in F<sub>3</sub>. All of the intermediates and 33 of the 45 *sativa* plants tested produced some pubescence on the upper as well as on the lower kernel. The data are complete for family 437a2, and only 6 plants failed to produce some hairs on the upper kernel out of 25 so classified in the preceding generation.

The  $F_3$  behavior of these one-kernel-pubescent sorts indicates that they are probably all potentially pubescent on both kernels, but that environment or some modifying gene has affected their development.

*Basal pubescence.*—The wild parent has a ring of short heavy hairs growing out of the collar or callus which surrounds the base. The hairs are approximately  $\frac{1}{16}$  inch long and are referred to as short. The *sativa* parent has a smooth base except for an occasional hair. In

examining the parental material only two such hairs were found, and these were  $\frac{1}{8}$  inch in length.

The  $F_1$  was pubescent but not so much as was the wild parent, there being a small tuft of hairs on each side of the base. The length was slightly longer than in the wild parent, and approximated that found in the *sativa* parent, though in some cases it was slightly longer than  $\frac{1}{8}$  inch.

The complete  $F_2$  data for the inheritance of this character are given in Table 4, in which it is noted that a new type of pubescence, designated long, has appeared. Those classified as long usually ranged from  $\frac{3}{16}$  to  $\frac{1}{4}$  inch in length, though in some cases there seemed to be no sharp line of demarkation between this and the intermediate length, one blending into the other. The intermediate and short classes are grouped together in the table.

TABLE 4.—Showing the inheritance of basal pubescence in  $F_2$  in a cross of *A. sativa* var. *Aurora*  $\times$  *A. sterilis* *Ludoviciana*.

Basal articulation	Length of basal hairs		
	Short	Long	None
Wild.....	150	64	—
Intermediate.....	302	124	2
<i>Sativa</i> .....	164	15	47
Total.....	616	203	49

The summary at the bottom of Table 4 indicates a 3:1 relationship between short and long, but with a non-pubescent group in addition. When this material was first classified, a much larger number was found in this group, but these were checked again, using a lens and examining 15 to 20 kernels before they were finally listed as non-pubescent. Of these, 35 were in two families. All of these were grown for  $F_3$  and 32 of them gave some basal hairs in this generation, 23 being short and 9 long. It appears, then, that all probably carry a gene for pubescence and that they might be grouped simply for length. As seen in Table 5, omitting the three which showed no pubescence, a very close agreement for a 3:1 ratio is to be observed, the D/P. E.

TABLE 5.—Showing the inheritance of basal pubescence in certain  $F_2$  families, 437a1 and 437a2, of a cross between *A. sativa* var. *Aurora* and *A. sterilis* *Ludoviciana*, the data being arranged in accordance with their behavior in  $F_3$ .

Basal articulation	Length of basal hairs		
	Short	Long	None
Wild.....	76	31	—
Intermediate.....	186	77	—
<i>Sativa</i> .....	118	12	3
Total.....	380	120	3

value being .77. The other  $F_2$  families were grown at Raleigh, N. C., and gave data similar to these, but the non-pubescent plants were not checked in  $F_3$ .

From an examination of the data in either Table 4 or Table 5, it appears that there is either a linkage relation or a modifying gene disturbing the normal segregation of short and long hairs in the wild and cultivated classes. It is hardly a case of linkage, however, as the wild parent has short basal hairs while from the data it would be expected that the reverse were true.

Within both the wild and intermediate groups there is a fair 3:1 ratio between short and long pubescence. The D/P. E. values for these two classes, from the data in Table 5, are 1.43 and 2.37, respectively. In the *sativa* class, however, the number of plants with long pubescence is greatly reduced. If  $\chi^2$  is calculated on a basis of six classes, omitting the three non-pubescent plants, a value for P less than .0002 is obtained.

It is concluded from the  $F_2$  and subsequent behavior of this character that there is a single-gene difference between long and short pubescence; that long pubescence is brought in by the *sativa* parent, but that in the parent and in the *sativa* groups in subsequent generations its appearance is modified by another gene associated with the *sativa* base.

#### STRENGTH OF AWN

The wild parent has two strong geniculate, twisted awns with a black basal portion, while the cultivated form is awnless except for an occasional weak awn.

The  $F_1$  was intermediate, producing one awn on all lower kernels but never on the upper; and that produced ranged from one that was geniculate and twisted to one that showed no twist and very little color at the base.

In  $F_2$  (Table 6), all wild plants bore two strong awns like the parent, while the cultivated groups exhibited a complete range from one strong awn to no awns. This was true in both the intermediate and *sativa* classes, but with the weak and awnless types predominating in the *sativa* class.

TABLE 6.—Showing the inheritance of strength of awn in  $F_2$  in a cross of *A. sativa* var. *Aurora*  $\times$  *A. sterilis* *Ludoviciana*.

Basal articulation	Number and strength of awns				
	2 strong	1 strong	1 intermediate	1 weak	None
Wild.....	214	—	—	—	—
Intermediate.....	—	209	147	69	3
<i>Sativa</i> .....	—	24	50	127	24
Total.....	214	233	197	196	27

As there were no sharp distinctions that could be drawn between the classes, it was hardly to be expected that definite ratios could be

obtained. It was noticed in the  $F_3$  breeding behavior of plants from these groups, that plants with one strong awn, would usually produce a complete range from strong to weak, that those of intermediate strength would tend to throw intermediates and weaks, and that the weak-awned plants tended to breed true or to throw a few plants with intermediate type of awn. This general behavior would indicate that possibly multiple genes were concerned if it were not for the fact that the parental types occurred in such large numbers in  $F_2$ .

Twenty-five of the awnless plants were tested in  $F_3$  and all produced some weak awns. This shows that all were potentially awned though for some reason they had appeared as awnless plants in  $F_2$ . Having a complete range from strong-awned to awnless plants indicates that environment influences the development of this character. In addition to environment, however, it also seems possible that some genetical modifier may influence the strength of awns and that this modifier is associated with the gene which determines the *sativa* type of base.

This relationship is further emphasized in the following study on percentage of awning (Table 7). These data were obtained by taking a single panicle from each plant in certain families and counting the number of awned and awnless spikelets. The strong-awned plants were usually 100% awned, thus giving a much higher number of fully awned plants in the intermediate group.

TABLE 7.—Showing the relation of basal articulation to percentage of awns in families 437a3, 437a4, and 437b1 in a cross of *A. sativa* var. *Aurora* × *A. sterilis* Ludoviciana.

Basal articulation	Percentage of awned spikelets						
	0	1-20	21-40	41-60	61-80	81-99	100
Wild.....	—	—	—	—	—	—	107
Intermediate.....	1	1	1	1	2	10	148
<i>Sativa</i> .....	2	3	3	6	16	23	40

The  $F_3$  data in general support those of the preceding generation.

#### MODIFYING FACTOR

The data presented indicate that there is a factor, or factors, associated with the *sativa* base which inhibits or modifies the full expression of genes for awns and basal pubescence on the lower kernel and dorsal pubescence on the upper kernel. If the data on strength of awn and length of basal hairs are studied together, there is some evidence that both characters are modified by the same gene.

It was mentioned previously that in the *sativa* group of families 437a1 and 437a2 there were 35 plants classified as having no basal hairs. Twenty-five of these occurred in the group of weak awns to awnless, as given in Table 8. It is to be noted further that while only 3 plants in the *sativa* group were classified as having long basal hairs in  $F_2$ , 12 were so classified when the  $F_3$  tests were completed. Of the nine plants with weak awns and long basal hairs found in  $F_3$ , seven

were from the weak and awnless groups and the other two from plants that had a very slight twist in the awn.

TABLE 8.—Showing the relation of basal articulation to strength of awn and to length of basal hairs in families 437a1 and 437a2 of a cross between *A. sativa* var. *Aurora* and *A. sterilis* *Ludoviciana*.

Basal articulation	Strength of awn and length of basal hairs								
	Strong			Weak			Awnless		
	Short	Long	None	Short	Long	None	Short	Long	None
F <sub>2</sub> Data									
Wild. ....	76	31	—	—	—	—	—	—	—
Intermediate. .	146	63	1	35	14	1	3	—	—
<i>Sativa</i> . . . . .	47	1	10	36	2	14	11	—	11
F <sub>3</sub> Data									
Wild. ....	76	31	—	—	—	—	—	—	—
Intermediate. .	148	63	—	38	14	—	—	—	—
<i>Sativa</i> . . . . .	55	3	—	62	9	3	—	—	—

In addition to a modifying gene associated with the *sativa* base, it is possible environment played a part in the appearance of these characters, as much of the F<sub>3</sub> testing of the awnless and non-pubescent plants was conducted at Raleigh, N. C., while the F<sub>2</sub> of the same families had been grown at Ithaca, N. Y. While it might seem that environment would affect their appearance and development in the wild, intermediate, and *sativa* types in much the same way, actually most of the modification seemed to be in the *sativa* group.

There is a morphological difference in the parental types which should be taken into consideration in the study of basal pubescence and that is suitable tissue from which the hairs can be produced. It was mentioned in the description of the base that in the wild parent there is a collar or callus surrounding it, and it is from this callus that a heavy band of basal hairs is produced. In the intermediate plants, the callus largely disappears, though the base is not contracted so much as in the *sativa* parent. The intermediates have a limited amount of pubescence, while in the *sativa* group it appears as only a trace or not at all. Possibly the difference in abundance of dorsal hairs on the lower and upper kernels may be explained in the same manner. The flowering glumes of the wild plants are coarse and ribbed. On intermediate and *sativa* plants this condition is found on the lower kernel but with the upper kernel almost smooth, especially in the *sativa* group.

Assuming that the basic genes are present, it seems possible that the amount of dorsal and basal hairs may be correlated with the abundance of suitable tissue for their development. A purely genetical gene or genes are, however, probably responsible for any modification of length of basal hairs which may take place, and the same genes possibly affect strength of awn. Such genes, together with environ-



ment, produce plants in the *sativa*-group which usually have very weak or no awns and only traces of short hairs or no basal pubescence.

#### OCCURRENCE OF *A. fatua* AND OTHER IRREGULAR TYPES

In the  $F_2$  of family 437 a4, as mentioned earlier, a few *fatua*-like plants appeared, the complete segregation giving 146 cultivated: 63 wild *sterilis*: 4 *fatua*. The kernels of these four plants were black and dorsally pubescent and the spikelets bore two strong awns. They seemed to differ from the *sterilis* group only in articulation and size of kernel, the *fatua* forms being much more slender than the *sterilis*. The following year each of the four *fatua* plants bred true, but of 20 *sterilis* plants taken from this family no *fatua* segregates were found. If there had been normal segregation for *sterilis* and *fatua* in the wild group, some of the next generation families would probably have segregated 15 *sterilis*: 1 *fatua*, and others 3 *sterilis*: 1 *fatua*. Since no such segregation was observed, and as similar forms had not been found in any of the other four  $F_2$  families, it was thought possible that these four plants were due to mechanical mixture.

In family 437a1 however, plant 116 was somewhat different from any other plant and among its progeny *fatua* segregates did occur. This plant had glabrous lemmas but was darker red in color than any other plant so classified. If it had been pubescent it might possibly have been grouped with the blacks. In  $F_3$  an almost complete range of colors, from black to yellow, was found, including a number of reddish-grey and three pure grey-kerneled plants. Twenty-three plants, representing the various color shades, were chosen and planted to observe their behavior in  $F_4$ . A tabulation of the results secured shows that the black sorts produced only black, red, and yellow, while the red and reddish-grey plants occasionally threw grey. One of the grey plants segregated in  $F_4$  for grey and yellow, while the other two gave a range from reddish-grey to yellow.

In three of these  $F_4$  families *fatua* segregates were found. In family 437a1-116-62, which was intermediate in  $F_3$ , there was a segregation of 27 cultivated: 10 *fatua*, and in each of the other two families, 437a1-116-11 and 437a1-116-57, the segregation was 18 wild *sterilis*: 4 *fatua*. These *fatua* plants all had two strong geniculate awns, were dorsally pubescent, and had heavy basal pubescence, but were grey in color instead of black.

Fifteen plants were taken from family 437a1-116-62 and planted. Of this number 2 bred true for *sativa*, 9 segregated, and 4 bred true for *fatua*. A total of the segregating families shows 176 cultivated to 47 *fatua*. From the other two families very nearly a complete  $F_5$  was grown. Of 40  $F_5$  families, 13 bred true for *sterilis*, 19 segregated, and 8 bred true for *fatua*, with slight irregularities in four of these. A summary of the segregating families gives 158 *sterilis* to 48 *fatua*. In the first case we have a fairly close 3:1 ratio for *sativa* and *fatua* and in the latter for *sterilis* and *fatua*.

A study of the *fatua* forms in these three families, as given in Table 9, shows a close linkage between the factors for *fatua*-type articulation and dorsal pubescence. All 18 *fatua* plants had heavy pubescence on

both kernels, while in the non-*fatua* groups a few plants produced a trace of pubescence, and this usually on the lower kernel only. The breeding behavior in  $F_3$  was in agreement, all *fatua* plants being pubescent and the non-*fatua* plants having only a trace to no pubescence.

TABLE 9.—Showing an apparent linkage relationship between factors for *A. fatua* type of articulation and dorsal pubescence in certain  $F_4$  families in a cross of *A. sativa* var. *Aurora* and *A. sterilis* *Ludoviciana*.

Family	Non- <i>fatua</i>		<i>Fatua</i>	
	Non-pubescent	Pubescent	Non-pubescent	Pubescent
11.....	15	3	0	4
57.....	15	3	0	4
62.....	22	5	0	10
Total.....	52	11	0	18

In a review of the literature no reference was found to a linkage of these factors. In *fatua* forms, pubescence has usually been found linked with black color and this independent from basal articulation.

Each of the *fatua* plants found in  $F_4$  also had grey-colored lemmas, while in the non-*fatua* group the color varied from reddish-grey to yellow. In this connection it should be mentioned that seeds from the parent plants of these three families were planted because they carried factors for grey color. If there was any linkage between the factors for grey color and *fatua* articulation, it was very weak. Three reddish-grey and one pure grey-kerneled  $F_3$  plant failed to produce any *fatua* plants in  $F_4$ . Further, there seems to be independent segregation of factors for grey color and pubescence in the non-*fatua* groups of these three families and in other grey-colored families.

Unfortunately, the  $F_3$  material did not develop good colors, and it was impossible to classify them correctly. The colors varied from reddish-grey to yellow.

The breeding behavior of these forms indicates that they originated through some chromosome aberration rather than natural crossing. The latter could not have accounted for the four *fatua* plants which occurred in the  $F_2$  of family 437a4 as such a cross would necessarily have been between the *sativa* parent and an *A. fatua* plant and would have been expected to produce 3 cultivated: 1 *fatua* plant in  $F_2$ .

In the case of family 437a1, a cross between a single flower of the  $F_1$  and an *A. fatua* plant, carrying factors for grey and pubescence, might have occurred. In this case, however, we would have expected a segregation of *sativa* and *fatua* or *sterilis* and *fatua* types in  $F_3$ , but *fatua* forms were not found until  $F_4$ .

In  $F_3$ , the behavior in most cases agreed with that expected, but in four families there were irregularities which would not be expected in normal segregating families. These four all appeared to be true *fatua* types in  $F_4$ , which was the recessive. In family 437a1-116-11, plant 7 gave 11 *fatua*: 2 *sterilis* and plant 22 produced 15 *fatua*: 1

*sterilis*. In family 437a1-116-57, plant 12 gave 4 *fatua*: 1 *sativa*: 1 *sterilis*; and in family 437a1-116-62, plant 7 produced 8 *fatua*: 1 *sativa*.

The series of irregular types of breeding behavior observed in this family, beginning with an off-colored, glabrous plant in  $F_2$ , the appearance of grey color in  $F_3$ , of *fatua*-type articulation linked with pubescence in  $F_4$ , and finally with the segregation of dominant types, *sativa* and *sterilis*, from *fatua* forms in  $F_5$ , would seem to be good evidence of chromosome aberration rather than natural crossing.

### SUMMARY

Studies on the inheritance of certain kernel characters and linkage relations in a cross between *A. sativa* var. Aurora and *A. sterilis* *Ludoviciana* have been reported in this paper.

1. The cultivated type of basal articulation is dominant to the wild, with the intermediate forms usually distinguishable giving a 1:2:1 ratio.

2. The kernels of the wild forms are brown or reddish black and those of the cultivated are yellow. In  $F_1$  these were black, while in  $F_2$  there was a segregation for black, red, and yellow in numbers approximating a 12:3:1 ratio, with the gene for red linked with that for wild-type articulation. No yellow-kerneled plants were found with the wild-type base in a total  $F_2$  population of 868, but in  $F_3$  1 plant with intermediate-type articulation was yellow and bred true for this color in  $F_4$ .

3. Genes for dorsal pubescence and black color showed complete linkage in  $F_2$  and  $F_3$ . These dorsal hairs appear in abundance on both kernels of wild, black-kerneled plants. In the cultivated groups, and especially in the true *sativa* group, dorsal pubescence is fairly abundant on the lower kernel but appears as a trace to none on the upper.

4. The wild parent has a heavy ring of short hairs surrounding the base of the lower kernel. These are produced on the collar or callus which surrounds the base. The cultivated parent has a smooth base except for an occasional hair, intermediate in length. The  $F_1$  produced a tuft of hair on each side of the base, intermediate in length. In  $F_2$  a new type of basal hairs, designated long, appeared. The intermediate forms were grouped with those with short pubescence, giving a ratio approximating 3 short: 1 long. This ratio held within either the wild or intermediate group, but in the *sativa* group very few plants produced long basal hairs. It is assumed that the gene for long pubescence was brought in by the cultivated parent, but in the parental material and in the *sativa* groups its appearance is inhibited or modified by an inhibitor associated with the gene which determines the *sativa* type of base.

5. The wild parent has two strong awns and the cultivated is smooth except for an occasional weak awn on the lower kernel. The  $F_1$  produced one awn, varying in strength from twisted and geniculate to weak. In later generations the wild plants always bore two strong awns like the parent, showing linkage of these two factors. In the

cultivated groups only one awn was produced and showed a complete range of types, from strong, twisted, and geniculate, to weak or awnless. The data indicate that the same inhibitor which affects basal pubescence also modifies awns. Possibly environment may also have affected the development of this character.

6. A summary of all these studies shows a very close linkage relationship between genes for the wild *sterilis* base, red color of kernel, and two strong awns. In addition, heavy basal pubescence is also associated with the wild type of base and has been explained on the fact that the wild oats have a callus from which the hairs are produced. This is absent in the *sativa* parent. There is no evidence of linkage of genetic factors which determine length of basal pubescence and basal articulation.

7. One  $F_2$  and three  $F_3$  families produced a few *fatua*-like plants which apparently originated through some chromosome aberration.

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## THE RELATION BETWEEN SINGLE AND DOUBLE CROSS YIELDS IN CORN<sup>1</sup>

D. C. ANDERSON<sup>2</sup>

WHEN four inbred lines have been selected to be used in a double cross, it is necessary to know which two single crosses, out of the possible six, should be used as parents to make the most productive double cross. Jenkins<sup>3</sup> presented data on four methods of estimating the yield of double crosses. These methods in brief consisted of (a) predicting the yield of the double cross on the basis of the average yield of the possible six crosses of the four inbred lines used in making the double cross; (b) predicting the yield on the basis of the average yield of the four single crosses not used in making the double cross; (c) prediction based on the average yield of the four inbred lines in all possible combinations with 10 other inbreds and these four averages averaged; (d) prediction based on the average yields of four inbred lines in top crosses.

The actual yield of 42 double crosses was correlated with the predicted, based on each of the four methods. Correlation coefficients calculated for actual yields related to predicted yields by methods A, B, C and D were 0.75, 0.76, 0.73, and 0.61, respectively, with a significant value represented by 0.39. Jenkins concludes that method D, while not as reliable, may be used fairly satisfactorily.

Doxtator and Johnson<sup>4</sup> emphasized the importance of predicting the best method of combining four lines in single and double crosses, especially in those cases where the single crosses differed widely in yields, and showed that method B of Jenkins could be used reliably in such cases. The top-cross method is now being used widely to select inbred lines on the basis of their combining ability. After making first crosses between these lines, one may then predict which combinations of each group of four lines can be used advantageously in making the single and double crosses for commercial use.

The present paper gives further evidence regarding the prediction of double cross yields from the yields of single crosses using method B as outlined by Jenkins. All possible 10 crosses have been studied between five inbred lines and the yields of the single crosses have been used to predict the best possible double cross from each group of four inbred lines.

<sup>1</sup>Contribution from the Division of Agronomy and Plant Genetics, University of Minnesota, St. Paul, Minn. Paper No. 1559 of the Journal Series, Minnesota Agricultural Experiment Station. Also presented at the annual meeting of the Society held in Chicago, Ill., December 1 to 3, 1937. Received for publication December 6, 1937.

<sup>2</sup>Instructor.

<sup>3</sup>JENKINS, MERLE T. Methods of estimating the performance of double crosses in corn. *Jour. Amer. Soc. Agron.*, 26:199-204. 1934.

<sup>4</sup>DOXTATOR, C. W., and JOHNSON, I. J. Prediction of double cross yields in corn. *Jour. Amer. Soc. Agron.*, 28:460-462. 1936.

## MATERIAL AND METHODS

The data reported in this paper were obtained in 1937 at the University Southeast Experiment Station, Waseca, Minn. The 10 single crosses made from five inbred lines and the 15 double crosses made from these 10 single crosses were used in this study. The five inbred lines used in making these crosses were 23 and 24, two late inbreds from Reid's Yellow Dent, and 26, 27, and 28, three inbreds of medium maturity from Golden Glow. All of these lines have been inbred for at least 10 years. The 10 single crosses and three check strains were grown in randomized blocks. Four replications were made, each plot consisting of a single row 18 hills long. Only three-stalk hills surrounded by corn were harvested and the yields calculated on a perfect stand basis. Five replications of the 15 double crosses and the three check strains were grown in another randomized block trial in the same field. Single-row plots 18 hills long were used. In two replications, five seeds were planted per hill and later thinned to three plants each and only three-stalk hills surrounded by corn were harvested. In the other three replications three seeds were planted per hill and the entire row was harvested, disregarding stand. The interaction between the two tests was computed and found to be non-significant so the five replications were averaged together.

Significant differences were computed in bushels for each of the two trials and are given in the tables. These are based on differences of two times the standard error of a difference.

## EXPERIMENTAL RESULTS

Yields of the 10 possible single crosses between the five lines are given in Table 1. The differences in yielding ability are highly significant. It would be expected then that there would be a significant difference in the yields of the double crosses.

TABLE 1.— *Yield of single crosses*

Cross	Bushels per acre	Cross	Bushels per acre
(23×24).....	41.7	(24×27).....	72.1
(23×26).....	62.6	(24×28).....	69.3
(23×27).....	70.8	(26×27).....	64.2
(23×28).....	64.4	(26×28).....	60.4
(24×26).....	65.6	(27×28).....	59.6

Difference required for significance 6.84.

Table 2 gives the actual and predicted yields for each of the 15 double crosses. The three different double crosses that can be made from four inbred lines are grouped together in the table. The predicted yield of the double cross was obtained by averaging the four single crosses not used as parents. For example, the predicted yield of the double cross (23×24) (26×27) would be the average of the four single crosses (23×26), (23×27), (24×26), and (24×27) which is 67.8 bushels. This is theoretically the highest yielding double cross that can be made with these four inbred lines. Actually it was the highest, yielding 68.8 bushels per acre as compared to 62.4 bushels for (23×26) (24×27) and 62.0 bushels for (23×27) (24×26). These yields agreed very closely to the ones arrived at by prediction.



The predicted yield of (23x24) (26x28) and the actual yield are about the same, being respectively 65.0 and 65.5 bushels, while the other two combinations of 23, 24, 26, and 28 gave significantly lower predicted and actual yields.

TABLE 2.—*Actual and predicted yield of double crosses.*

Cross	Bushels per acre		Cross	Bushels per acre	
	Actual	Predicted		Actual	Predicted
Lines combined, 23, 24, 26, 27			Lines combined, 23, 26, 27, 28		
(23×24) (26×27)	68.8	67.8	(23×26) (27×28)	68.2	65.0
(23×26) (24×27)	62.4	60.6	(23×27) (26×28)	65.0	62.7
(23×27) (24×26)	62.0	60.2	(23×28) (26×27)	65.7	63.4
Lines combined, 23, 24, 26, 28			Lines combined, 24, 26, 27, 28		
(23×24) (26×28)	65.0	65.5	(24×26) (27×28)	70.2	66.5
(23×26) (24×28)	59.8	58.0	(24×27) (26×28)	62.0	64.7
(23×28) (24×26)	56.0	58.5	(24×28) (26×27)	62.7	64.4
Lines combined, 23, 24, 27, 28					
(23×24) (27×28)	71.1	69.2			
(23×27) (24×28)	58.1	59.4			
(23×28) (24×27)	58.0	60.4			

Difference required for significance, actual, 5.26

Difference required for significance, predicted, 3.41

In a similar way it may be seen that the combination of (23x24) (27x28) gave much higher predicted and actual yields than any other combinations of these four lines. Differences were not so great in the predicted yields of 23, 26, 27, and 28 in combination and the actual yields were not widely different. The predicted yields for 24, 26, 27, and 28 in combination were not significantly different, although in this case one combination of the four lines yielded significantly better than the other two.

The coefficient of correlation computed between the actual and the predicted yield of the 15 double crosses,  $r = .90$ , is highly significant.

#### SUMMARY

The actual yield of 15 double crosses and the predicted yield as obtained by averaging the yield of the four single crosses not used as parents were compared. The results show a close agreement between the predicted and the actual yield of the double crosses.

If top crosses are used to pick out inbred lines for testing in double cross combinations, it is apparent from these results that it is highly desirable to study all possible single crosses between each of four lines in order to determine how they should be combined.

## ROW SPACING AND RATE OF SEEDING FOR RICE NURSERY PLATS<sup>1</sup>

N. E. JODON and H. M. BEACHELL<sup>2</sup>

IN America the same technic is followed in conducting yield tests with rice as with other small grains, except that the land is submerged during the most of the growing season. A departure from the conventional three-row nursery plat with the rows 12 inches apart and only the center row harvested for yield would appear to have the following possible advantages: (a) Less space between rows would more nearly approximate the usual farm practice and give better control of weeds and grasses; (b) in 36-inch or 40-inch plats with rows spaced 6, 8, or 10 inches apart, four, three, or two inside rows could be harvested and the larger proportion of the plat harvested should tend to reduce variability; (c) a better distribution of plants over the area sown in rows more closely spaced might also tend to increase yields; and (d) additional seed would be available for more extensive tests.

Possible disadvantages in spacing rows less than 12 inches apart are (a) difficulty in seeding on rough seedbeds; (b) difficulty in weeding and roguing on submerged land; and (c) increased plant competition for light and nutrients.

Similar experiments herein reported were conducted in 1936 at the Rice Experiment Station, Crowley, Louisiana, and the Texas Agricultural Substation No. 4, Beaumont, Texas, to study the effect of closer spacing between rows on yield and variability.

### PROCEDURE AND EXPERIMENTAL CONDITIONS

The split strip experimental design was used to permit a study of the distribution of the seed into rows 6, 8, 10, and 12 inches apart for each rate of seeding. Plats for the 6-inch spacing were six rows wide, those for the 8-inch spacing were five rows wide, those for the 10-inch spacing were four rows wide, and those for the 12-inch spacing were the usual three rows wide.

The experiment at each location comprised four blocks. Each block consisted of 16 plats involving the 16 possible combinations of four varieties with four rates of seeding. Each plat was subdivided into four sub-plats for the four-row spacings. The varieties used were Caloro (medium to early), Fortuna (medium maturity), Blue Rose (late), and Rexoro (very late). The rates of seeding were 60, 80, 100, and 120 pounds per acre. At Crowley the four blocks were arranged in a square, but at Beaumont they were in a single series. Limited transplanting was necessary to obtain uniform stands in certain plats at Crowley, but at Beaumont the stands were as nearly perfect as could be expected.

The plats at Crowley were sown May 4 and 5, the seedlings were fully emerged about May 24, and the land was submerged June 8. Water was maintained on the

<sup>1</sup>Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, in cooperation with the Louisiana and Texas Agricultural Experiment Stations. Received for publication December 4, 1937.

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field until Rexoro ripened. At Beaumont the plats were sown on April 20 and 21 and were irrigated and immediately drained on April 25 and again on May 6. The land was submerged June 9, resubmerged on June 22 after the soil had dried, and a normal depth of water was maintained thereafter throughout the growing season. All varieties, except Rexoro, were harvested before draining the water from the plats.

In the area used for the experiment at Crowley, three levees running in the same direction as the plats had been leveled more than a year before the experiment was conducted. Growth was poorest on the bases of the old levees and best on the sides. This land (Crowley silt loam) had been in rice and soybeans alternately from 1916 to 1930, and rice and fallow in alternate years beginning 1930. No fertilizer had ever been applied.

The area used for the experiment at Beaumont was Crowley clay, dark phase, and was of uniform topography. The land was cropped to rice in 1925 and 1926, to soybeans in 1927, to cotton in 1928, and was summer fallowed in 1929. During the period of 1930-1933, inclusive, the land was planted to corn in the early spring and followed by a leguminous crop in the fall. The corn was fertilized each season, but no record is available as to the amount or composition of the fertilizer applied. The area was cropped uniformly to rice in 1934 and summer fallowed in 1935.

The mean annual rainfall at Crowley is 55.97 inches and in 1936 the total was 41.54 inches. The mean for the growing season, April to September, inclusive, is 28.51 inches, and the total in 1936 was 22.82 inches. The corresponding rainfall at Beaumont was 53.71 and 48.48 and 28.06 and 32.08 inches, respectively. The seasonal weather conditions at the two stations usually are not greatly different because the stations are only about 120 miles apart with about 10 miles difference in latitude and both are within 50 miles of the Gulf of Mexico.

## RESULTS

The yield data in bushels per acre by individual sub-plats, together with the means of each of the 64 combinations of varieties with rates and spacings, are given in Table 1. The mean yield of the rice in the experiment at Crowley was 32.8 bushels per acre and at Beaumont 54.5 bushels. The *F* values (4)<sup>3</sup> from the analysis of variance (Table 2) show that the differences among the varietal yields were highly significant at each station. Rexoro, Fortuna, and Caloro produced considerably higher mean yields than did Blue Rose (Table 3). The mean yield of Blue Rose was 6.1 to 9.8 bushels less than that of the other varieties at Crowley and 13.5 to 14.9 bushels less at Beaumont.

The small differences in mean yields from the different rates of seedling were not significant. At Crowley there was a maximum difference of 3.7 bushels between plats with rows spaced 6 inches apart and those with wider spacings. There was a consistent increase in yield as the space between the rows was reduced from 12 to 6 inches. The analysis of variance indicates that the odds are considerably higher than 99:1 that the yield differences from the variations in spacing at Crowley were significant. At Beaumont, however, the differences were very small and not significant.

The interactions, varieties x rates, spacings x varieties, spacings x rates, and spacings x varieties x rates were not significant. The mean

<sup>3</sup>Figures in parenthesis refer to "Literature Cited," p. 219.

TABLE 1.—*Plat yields in bushels per acre from varieties, rates, and spacings.*

Rate of seeding, lbs.	Row spacing, in.	Acre yield in bushels									
		Crowley, La., blocks					Beaumont, Texas., blocks				
		1	2	3	4	Mean	1	2	3	4	Mean
Caloro											
60	6	34.0	28.5	29.9	27.6	30.0	54.6	56.0	53.4	57.2	55.3
	8	26.9	29.5	28.1	39.6	31.0	56.5	59.0	60.3	62.5	59.6
	10	33.5	32.2	29.1	29.1	31.0	55.4	69.8	60.0	61.4	61.7
	12	21.3	26.9	29.3	29.9	26.9	46.4	59.4	56.6	60.8	55.8
80	6	28.4	31.5	31.5	39.3	32.7	41.3	53.4	59.2	52.5	51.6
	8	30.0	30.1	34.5	32.8	31.9	46.3	51.4	60.0	73.0	57.7
	10	27.5	31.4	34.9	37.0	32.7	52.9	59.1	64.9	61.0	59.5
	12	28.3	30.4	26.7	36.5	30.5	57.5	65.9	59.4	74.0	64.2
100	6	31.3	36.0	36.5	46.4	37.6	46.4	55.4	55.2	55.9	53.2
	8	28.1	42.1	35.3	37.7	35.8	52.6	59.2	63.9	56.0	57.9
	10	25.4	32.2	33.1	40.2	32.7	64.6	57.0	59.0	57.9	59.6
	12	37.1	27.7	30.1	32.0	31.7	58.3	66.6	55.1	52.2	58.1
120	6	40.3	42.5	33.1	39.7	38.9	74.2	55.8	55.4	64.4	62.5
	8	31.5	42.9	34.1	33.6	35.5	67.8	61.6	61.4	59.2	62.5
	10	34.4	38.4	37.6	34.7	36.3	70.1	61.9	55.9	49.1	59.3
	12	27.5	33.3	31.5	38.1	32.6	69.2	57.8	64.2	55.1	61.1
Fortuna											
60	6	24.8	34.4	38.3	39.2	34.2	62.4	58.2	63.0	64.7	62.1
	8	32.7	24.7	37.3	43.2	34.5	36.3	61.5	56.8	51.1	51.4
	10	25.8	26.6	40.3	34.7	31.9	54.9	49.4	54.5	51.3	52.5
	12	29.6	26.4	29.9	36.8	30.7	48.4	57.4	54.4	52.3	53.1
80	6	36.4	42.4	31.9	41.3	38.0	47.3	61.8	56.2	61.4	56.7
	8	35.2	34.8	30.8	27.1	32.0	55.0	54.5	64.0	54.4	57.0
	10	28.5	32.8	30.7	32.7	31.2	53.3	56.2	61.4	57.9	57.2
	12	25.3	42.9	23.7	29.9	30.5	59.1	60.3	53.1	59.5	58.0
100	6	37.2	28.1	46.8	35.2	36.8	55.0	55.5	61.4	63.0	58.7
	8	27.1	38.4	34.5	42.0	35.5	50.2	57.6	59.4	57.4	56.2
	10	39.4	37.5	41.6	35.7	38.6	60.7	59.7	58.5	63.4	60.6
	12	44.5	31.7	36.3	34.4	36.7	62.0	56.0	62.6	48.8	57.4
120	6	27.3	45.3	43.7	41.1	39.4	64.8	61.8	59.6	70.0	64.1
	8	31.5	31.1	45.2	39.2	36.8	48.3	60.0	56.8	67.0	58.0
	10	25.6	29.8	47.5	37.0	35.0	49.6	58.7	56.3	64.7	57.3
	12	22.9	38.1	34.9	34.1	32.5	53.4	49.5	56.0	66.7	56.4

yields for comparison of varieties, rates of seeding, and row spacings in combinations of two each are shown in Table 4. Since the F values of the interactions are not significant, there are no significant differences among these means, nor among the means of the variety-rate-spacing combinations shown in Table 1.

#### DISCUSSION OF RESULTS

The mean yield of all plats in the experiment at Beaumont exceeded that of the experiment at Crowley by 21.7 bushels. The larger yields

TABLE I.—*Continued.*

Rate of seeding, lbs.	Row spacing, in.	Acre yield in bushels									
		Crowley, La., blocks					Beaumont, Texas., blocks				
		1	2	3	4	Mean	1	2	3	4	Mean
Blue Rose											
60	6	26.9	27.5	26.4	27.6	27.1	41.5	47.4	37.3	47.5	43.4
	8	25.3	24.0	23.9	28.0	25.3	42.4	43.3	39.9	46.9	43.1
	10	21.8	27.2	20.5	33.0	25.6	31.4	49.5	45.9	52.7	44.9
	12	24.3	24.3	24.8	26.1	24.9	39.6	46.0	41.5	41.7	42.2
80	6	28.0	32.9	26.8	28.1	29.0	50.2	43.3	43.9	51.8	47.3
	8	23.5	38.1	24.3	30.9	29.2	46.5	46.9	45.0	49.2	46.9
	10	22.7	29.1	23.7	26.1	25.4	39.4	40.9	39.8	52.2	43.1
	12	21.1	27.2	23.2	26.9	24.6	40.5	47.1	45.1	50.2	45.7
100	6	29.7	28.7	31.6	29.1	29.8	42.7	41.3	45.3	44.0	43.3
	8	28.4	32.7	28.4	25.3	28.7	42.7	42.6	42.5	40.7	42.1
	10	28.0	25.9	23.8	30.4	27.0	54.8	48.5	43.9	45.5	48.2
	12	21.1	25.6	27.5	30.1	26.1	51.2	39.1	44.1	40.9	43.8
120	6	28.4	28.8	31.6	27.1	29.0	37.7	43.6	40.1	43.7	41.3
	8	26.0	27.3	27.6	28.8	27.4	44.1	44.7	35.3	39.9	41.0
	10	24.2	29.5	25.8	24.5	26.0	39.5	38.4	41.5	44.7	41.0
	12	19.5	24.8	29.6	28.5	25.6	43.6	40.3	42.8	45.3	43.0
Rexoro											
60	6	33.7	50.2	30.9	46.5	40.3	44.7	55.8	60.3	52.5	53.3
	8	47.5	39.9	36.0	37.5	40.2	54.3	63.0	64.4	44.5	56.6
	10	43.2	44.0	31.5	42.1	40.2	52.7	59.2	64.9	45.5	55.6
	12	34.4	38.1	29.3	28.8	32.7	60.3	68.7	55.5	53.0	59.4
80	6	38.4	40.0	28.3	39.2	36.5	53.5	62.3	58.7	61.8	59.1
	8	38.3	38.5	30.5	41.6	37.2	61.0	60.0	63.6	61.8	61.6
	10	34.6	35.1	29.3	36.3	33.8	59.2	62.6	61.8	50.8	58.6
	12	41.1	35.7	18.4	54.2	37.4	50.2	57.6	56.6	61.6	56.5
100	6	37.3	39.2	36.7	41.1	38.6	59.0	59.0	64.0	48.5	57.6
	8	37.9	39.1	27.2	44.9	37.3	55.8	63.2	59.8	62.0	60.2
	10	37.8	32.7	29.6	39.1	34.8	59.0	64.0	60.2	63.6	61.7
	12	34.1	28.8	32.8	47.5	35.8	59.1	63.8	62.2	59.6	61.2
120	6	31.2	39.5	39.7	30.1	35.1	55.9	58.3	56.2	62.2	58.2
	8	32.3	41.3	42.3	41.1	39.3	53.0	62.7	57.8	57.6	57.8
	10	32.2	41.0	38.3	27.1	34.7	49.5	61.6	58.0	60.1	57.3
	12	31.2	44.0	33.9	25.3	33.6	59.4	57.5	61.2	59.5	59.4
General mean					32.8					54.6	

at Beaumont were probably due to a higher state of soil fertility and are in line with other yields obtained from the same varieties.

The analysis of the main plats shows an essential agreement between the two tests. There was greater soil variation at Crowley as shown by the significant variance among blocks. This may be due in part to the condition brought about by leveling the old levees in the

TABLE 2.—*Variance in the variety-rate-spacing experiment of 1936.*

Variation due to	Degrees of freedom	Sum of squares	Mean square	F
Crowley, Louisiana				
Block.....	3	668.70	222.90	3.98*
Variety.....	3	3,410.90	1,136.97	20.30†
Rate of seeding.....	3	251.75	83.92	1.50
Variety × rate.....	9	414.72	46.08	0.82
Error (a).....	45	2,519.98	56.00	—
Main plats.....	63	7,266.05	115.33	6.54†
Row spacing.....	3	510.97	170.32	9.66†
Spacing × variety.....	9	64.42	7.16	0.41
Spacing × rate.....	9	70.18	7.80	0.44
Spacing × variety × rate....	27	335.24	12.42	0.70
Error (b).....	144	2,540.27	17.64	—
Total.....	255	10,787.13		
Beaumont, Texas				
Block.....	3	427.92	142.64	2.64
Variety.....	3	9,971.03	3,323.68	61.41†
Rate of seeding.....	3	172.90	57.63	1.06
Variety × rate.....	9	430.90	47.88	0.88
Error (a).....	45	2,435.43	54.12	—
Main plats.....	63	13,438.18	213.30	10.91†
Row spacing.....	3	18.16	6.05	0.31
Spacing × variety.....	9	458.96	51.00	2.61
Spacing × rate.....	9	283.80	31.53	1.61
Spacing × variety × rate....	27	606.57	22.47	1.15
Error (b).....	144	2,815.52	19.55	—
Total.....	255	17,621.19		

\*Exceeds the 5% point.

†Exceeds the 1% point.

TABLE 3.—*Mean yields in bushels per acre for varieties, rates of seeding, and row spacings.*

Variety	Acre yields in bushels		Rates of seeding, lbs. per acre	Acre yield in bushels		Spacing between rows, in.	Acre yield in bushels	
	Crowley	Beaumont		Crowley	Beaumont		Crowley	Beaumont
Caloro.....	33.0	58.8	60	31.7	53.1	6	34.6	54.2
Fortuna.....	34.6	57.3	80	32.0	55.0	8	33.6	54.4
Blue Rose....	26.9	43.8	100	34.0	55.0	10	32.3	54.9
Rexoro.....	36.7	58.4	120	33.6	55.0	12	30.8	54.7

experimental area. The F value obtained for varietal differences was much greater in both experiments than is necessary for odds of 99:1.

TABLE 4.—Mean yields in comparison of varieties, rates of seeding, and spacings in combinations of two each.

	Crowley				Beaumont			
	Cal-oro	For-tuna	Blue Rose	Rex-oro	Cal-oro	For-tuna	Blue Rose	Rex-oro
Varieties and Rates								
60 lbs. per acre . . . .	29.7	32.8	25.7	38.4	58.1	54.8	43.4	56.2
80 lbs. per acre . . . .	31.9	32.9	27.0	36.2	58.2	57.2	45.8	58.9
100 lbs. per acre . . . .	34.5	36.9	27.9	36.6	57.2	58.2	44.4	60.2
120 lbs. per acre . . . .	35.8	35.9	27.0	35.7	61.4	59.0	41.6	58.2
Varieties and Spacings								
6-inch . . . . .	34.8	37.1	28.7	37.6	55.6	60.4	43.8	57.0
8-inch . . . . .	33.6	34.7	27.7	38.5	59.4	55.6	43.3	59.0
10-inch . . . . .	33.2	34.1	26.0	35.9	60.0	56.9	44.3	58.3
12-inch . . . . .	30.4	32.6	25.3	34.9	59.9	56.2	43.7	59.1
Rates and Spacings								
	60-lb. rate	80-lb. rate	100-lb. rate	120-lb. rate	60-lb. rate	80-lb. rate	100-lb. rate	120-lb. rate
6-inch . . . . .	32.9	34.0	35.7	35.6	53.5	52.7	53.2	56.5
8-inch . . . . .	32.8	32.6	34.3	34.7	52.7	55.8	54.1	54.8
10-inch . . . . .	32.2	30.8	33.3	33.0	53.7	54.6	57.5	53.7
12-inch . . . . .	28.8	30.7	32.6	31.1	52.6	56.1	55.1	55.1

Rate differences were not significant. In previous rate of seeding tests conducted at Crowley the 60-pound rates usually yielded somewhat less than the 80 and 100 rates (2). The interaction of varieties and rates also gave F values much below those necessary for odds of 19:1 that the differences were significant. Since the interaction of varieties and rates was not significant, it is clear that varietal differences were expressed equally over the full range of the rates of seeding used.

Analysis of the sub-plot yields for the purpose of comparing row spacings revealed that the spacing differences were highly significant at Crowley, but were not significant at Beaumont. The fact that other nursery yields from rows spaced 12 inches apart at Crowley have also averaged distinctly lower than the same varieties in field plats in which the spacing was 8 inches appears to confirm the Crowley results in this experiment. The spacing x variety and the spacing x rate interactions were not significant at either station, nor was the variety-rate-spacing interaction. This shows that the varieties responded in the same manner to the various combinations of rates of seeding and spacing.

Coefficients of variability computed from data on spacings in three years are shown in Table 5. In 1934 a less efficient experimental design was used. In 1935 two varieties only were included at Beaumont and certain plats were missing at Crowley, but the experiment was of the same design as the complete experiment of 1936. The coefficients of variability for spacings in 1934 were of about the same magnitude at both stations. In 1934 the experiments were on rather infertile soil



TABLE 5.—*Coefficients of variability from row spacing experiments, 1934 to 1936, inclusive.*

Location	Coefficient of variability, spacing in inches				
	6	8	10	12	Experiment
1934					
Crowley.....	18.3	17.0	15.0	21.1	18.1
Beaumont.....	15.3	17.3	16.6	22.2	17.9
1935					
Crowley.....	20.2	19.4	19.9	22.6	20.6
Beaumont.....	14.0	12.5	14.6	14.9	13.9
1936					
Crowley.....	18.1	18.7	18.8	22.4	19.8
Beaumont.....	15.2	15.9	15.1	15.1	15.2

at both stations. At Crowley there was general agreement in magnitude over the 3-year period. Coefficients from the Beaumont data, however, were distinctly lower in 1935 and 1936 than in 1934 for the 12-inch spacing. A more accurate distribution of seed may have in part accounted for this decrease in variability. Another possible factor was the higher state of fertility of the area used which would promote a greater equalizing growth of plants adjacent to missing areas. At Crowley rather dry conditions at time of emergence were partly responsible for somewhat uneven stands. They were, however, equal to stands ordinarily obtained in nursery tests.

Similar experiments, using transplanted rice, have been reported by Chakravertti, Bose, and Mahalanobis (1) in India. No significant differences were found among 6-inch, 9-inch, and 12-inch spacings between hills nor for one, two, or two to four plants per hill, except that yields from close spacing and a larger number of plants per hill were significantly higher when planting was delayed. Peh (3) in China, reporting on tests conducted on three crops grown in two years, found that the closer spacings gave significantly higher yields. Differences in numbers of plants per hill were not significant, but the interaction of spacing and number of plants were significant.

#### SUMMARY

Among nursery plats of approximately the same area, increasing the number of rows per plat, with a concomitant increase in the proportion of the plat harvested, increased the yields of rice and reduced the variability somewhat in experiments at Crowley, La., but had no significant effect at Beaumont, Texas.

Highly significant varietal differences were found at both stations by the analysis of variance. Rates of seeding varying from 60 to 120 pounds per acre did not affect the yields. At Crowley the plats with 6-inch intervals between rows gave significantly higher acre yields than did plats with wider spacings. On more fertile soil at Beaumont

spacing the rows from 6 to 12 inches apart did not influence acre yields. Where the yields of nursery plats, grown in rows spaced 12 inches apart, are consistently lower than those of the same varieties grown in field plats, the results at Crowley indicate that by allowing less space between the rows and by harvesting a larger proportion of the plat the nursery yield may be increased. This practice, however, would require more labor in seeding, harvesting, and threshing, and would make roguing more difficult.

Since none of the interactions was significant at either station, it appears that the varietal differences were expressed equally over the full range of seeding rates and spacings.

Coefficients of variability show that at Crowley the three-row plats with a 12-inch row spacing and with only the one center row harvested were slightly more variable than were plats of the same or similar size in which the rows were spaced more closely and two to four of the inside rows were harvested. At Beaumont the plat variability was practically the same regardless of the spacing between rows.

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## THE INHERITANCE OF PERICARP TENDERNESS IN SWEET CORN<sup>1</sup>

I. J. JOHNSON and H. K. HAYES<sup>2</sup>

THE present-day method of corn breeding has met with outstanding success in its application to sweet corn improvement. Many canning companies are now utilizing hybrids exclusively in the production of their commercial canning crop. The superiority of hybrids, in uniformity, productiveness, and in many cases resistance to destructive diseases, has resulted in this rapid change from open-pollinated varieties to hybrid strains. The improvement of quality in hybrids also ranks as a major problem. While many of the "quality" attributes in sweet corn are difficult to evaluate on a numerical basis, pericarp tenderness appears to lend itself to fairly accurate measurement. The need for tender pericarp hybrids is of special importance in meeting the demand for types suitable for whole ear as well as in whole kernel canning methods.

Detailed histological studies have been reported by Haddad<sup>3</sup> showing the changes which occur in the pericarp tissue during the development of the endosperm in sweet corn. Doxtator<sup>4</sup> has made a recent report of previous studies at the Minnesota Agricultural Experiment Station on the measurement of quality in sweet corn.

The present paper will present studies conducted since 1934 pertaining to the inheritance of pericarp tenderness in sweet corn.

### MATERIAL AND METHODS

Among the inbred lines used in the sweet corn improvement program, the strains obtained from the Crosby variety have exhibited a greater degree of pericarp toughness than those from 8-rowed Golden Bantam. The objection to the use of the Crosby variety has been based largely upon the toughness of its pericarp. A 4-year selfed Crosby inbred line, culture 1-30, used as one of the parents in Minhybrid 204, was selected as a typical tough pericarp line. An extremely tender pericarp, white endosperm, open-pollinated variety of unknown origin, was obtained from H. M. Hayes of Granby, Conn., who has grown it for home use for many years. This variety has a more tender pericarp than the most tender lines from Golden Bantam.

The measurement of pericarp tenderness was made with a puncture test machine similar to the one first described by Culpepper and Magoon<sup>5</sup>. All ears

<sup>1</sup>Contribution from the Division of Agronomy and Plant Genetics, University of Minnesota, St. Paul, Minn. Paper No. 1560 of the Journal Series, Minnesota Agricultural Experiment Station. Also presented at the annual meeting of the Society in Chicago, Ill., December 1 to 3, 1937. Received for publication December 8, 1937.

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<sup>3</sup>HADDAD, E. S. Morphological development of sweet corn pericarp in two inbred lines and their F<sub>1</sub> hybrid. Purdue Univ. Agr. Exp. Sta. Bul. 347. 1931.

<sup>4</sup>DOXTATOR, C. W. Studies of quality in canning corn. Jour. Amer. Soc. Agron., 29:735-753. 1937.

<sup>5</sup>CULPEPPER, C. W., and MAGOON, C. A. Studies upon the relative merits of sweet corn varieties for canning purpose and the relation of maturity of corn to the quality of the canned product. Jour. Agr. Res. 28:304-443. 1924.

were tested in hand-pollinated ears at 20 days after pollination or in open-pollinated ears 20 days after the first appearance of silks on the individual plants. Five or six kernels near the center of the ear were punctured to obtain an average value for any particular ear. This method was found to be rapid and applicable also to ears punctured on the plant when it was necessary to grow the ears to complete maturity.

The data included in this paper consist of measurements of puncture test values of the tough and tender pericarp parents, 1-30 and H, for the period 1934-37; the  $F_1$  cross (1×H) for the period 1934-35; the  $F_2$  generation for the 3-year period 1935-37; and backcrosses to the tender and tough pericarp parents in 1935. In addition to these data, a study was made in 1937 to test the breeding behavior of 34  $F_3$  lines and of 42 first generation selfed progenies from first backcrosses to the tender parent. From 40 to 60 ears were puncture tested in each progeny row. The plants were marked with a different colored tag to designate their date of first emergence of silks and the open-pollinated ears were puncture tested 20 days later. Seven rows of each of the two parents were also grown and tested as individual rows for the purpose of studying comparative variability of the parents in relation to the  $F_3$  and first year selfed progenies from the first backcross.

Typical examples, from the backcrosses used in the breeding studies for pericarp tenderness, will be used to illustrate the effect of selecting for tenderness in a backcross to the tough pericarp parent and to show the extent of recovery of the genotype of the tender parent in backcrosses to the tender parent.

The puncture tests of ears used in the breeding studies were made on the plant by stripping back a portion of the husks, puncturing the desired number of kernels, and replacing the husks to prevent premature drying of the kernels. The ear bag was also replaced further to protect the ear from damage. The data on inheritance of pericarp tenderness are summarized in two parts as somewhat different methods were used in taking the data. From 1934 to 1936, inclusive, puncture tests were made in the field on the plants and the occasional widely deviating measurement on a particular ear was discarded providing it was not obtained again in a second reading. The machine used for this work was more finely graduated than for the 1937 studies.

In the 1937 studies no readings were discarded. The ears were harvested and brought into the laboratory before taking the puncture readings. The data presented in Fig. 1 and Table 2 were taken in 1937 as described. All other data were taken in the field and the more finely graduated puncture test machine was used.

## EXPERIMENTAL RESULTS

### INHERITANCE OF PERICARP TENDERNESS

From the summary of the data on the inheritance of pericarp tenderness given in Table 1 it is apparent that the two parents, cultures H and 1-30, were consistently different in pericarp tenderness during the 3-year period 1934-36. The average difference in puncture test values between them was slightly over 100 units. The Crosby inbred line 1-30 gave a somewhat more consistent puncture test value from year to year and considerably less variability than the H parent, an open-pollinated variety. The  $F_1$  cross was made with pollen bulked from several plants of the tender parent to insure a representative average of its genotype. The average values for the  $F_1$  crosses studied in 1934 and 1935 were approximately intermediate between the two

parents not only in the mean puncture test value for the population but also in respect to variability. The frequency distribution of the  $F_1$  population and its mean would suggest a lack of dominance for either tender or tough pericarp.

The  $F_2$  data obtained on a rather limited basis in 1935 and more extensively in 1936 do not make it possible to decide regarding the number of genes which condition pericarp tenderness. While the  $F_2$  is somewhat more variable than  $F_1$ , the range in  $F_2$  in 1935 extended over only two more classes in the frequency table than did the  $F_1$ . The coefficient of variability obtained in the  $F_2$  population exceeded that for the  $F_1$  generation and also the open-pollinated tender pericarp variety during the comparable period in 1935 and 1936.

The backcross to the tender pericarp parent in 1935 gave a mean value midway between the tender pericarp parent and the  $F_1$  cross grown during the same season, indicating, as would be expected, the tendency partially to recover the genotype of the tender pericarp parent.

The backcross to the tough pericarp parent gave a higher mean puncture test value than the backcross to the tender parent but failed to show the partial recovery of the genotype of the tough parent. The mean value of 332 in this backcross was approximately equal to that of the  $F_1$  cross grown during the same year rather than midway between the  $F_1$  cross and the tough pericarp parent.

The data for 1937 for the two parents and an  $F_2$  generation is given in Fig. 1. Larger numbers of plants were tested in this study, the curves given being on the basis of an  $n$  value for H, 1-30, and the  $F_2$  of 390, 299, and 430, respectively. Mean values were  $293 \pm 1.19$ ,  $387 \pm 1.54$ , and  $352 \pm 1.99$  for the parents and  $F_2$ . In this study the  $F_2$  mean is somewhat higher than the average of the parents and some ears were obtained with slightly higher and lower puncture values than for the tough and tender pericarp parents, respectively.

The breeding behavior of  $F_2$  plants and first year selfed progeny of first backcrosses to the tender parent was determined by puncture testing from 40 to 60 ears from their progeny rows. Seven rows of each parent were also tested separately to compare the variability within and between rows of the parents in relation to the progenies. It should be remembered that these data and those given in Fig. 1 are taken in a comparable way, while the rest of the data were taken as described with a puncture test machine with finer graduations. The data from this test, summarized in Table 2, show that the coefficient of variability for rows of culture 1-30 ranged from 5 to 8% and for the open-pollinated H parent variety from 5 to 12%. Among the 34  $F_3$  lines from the cross of 1-30  $\times$  H, 12 progeny rows were no more variable than the 1-30 inbred parent, and all but two no more variable than the H parent, although their means differed greatly. The data from the  $F_3$  lines suggest that relatively homozygous tough pericarp strains were obtained more frequently than homozygous tender strains since 5 of the 12 low variability lines had the same mean puncture test value as the tough parent. No strains were obtained having as low a mean value as the tender parent with a coefficient of variation of the same magnitude as H. The recovery in  $F_3$  of relatively

TABLE 1.—Frequency distribution of puncture test values of parents,  $F_1$ ,  $F_2$ , and backcrosses to the two parents from a cross of tender  $\times$  tough pericarp sweet corn, 1934-36.

Culture	Year	Puncture test values										Total	Mean	C.V.
		240	260	280	300	320	340	360	380	400	420			
H parent.....	1934	11	18	19	11	5	1	—	—	—	—	65	275	9.0
	1935	—	13	40	46	13	7	—	—	—	—	119	293	6.9
	1936	14	28	33	6	1	—	—	—	—	—	82	268	6.7
I-30 parent.....	1934	—	—	—	—	—	—	4	26	42	5	77	392	3.5
	1935	—	—	—	—	—	—	11	40	37	4	92	387	3.9
	1936	—	—	—	—	—	—	11	46	43	—	100	386	3.4
(1-30 $\times$ H) $F_1$ .....	1934	—	—	—	5	27	31	14	7	1	—	85	339	6.4
	1935	—	—	—	6	40	44	4	1	—	—	95	330	4.4
(1-30 $\times$ H) $F_2$ .....	1935	—	—	1	9	23	20	16	8	2	—	79	338	7.8
	1936	—	3	19	40	40	24	8	2	—	—	136	314	7.8
(1-30 $\times$ H) $\times$ H.....	1935	—	3	15	28	22	13	7	3	—	—	91	313	8.8
(1-30 $\times$ H) $\times$ I-30.....	1935	—	—	4	12	23	23	15	4	1	—	82	332	7.7

homozygous lines having a mean puncture test value intermediate to the two parents strongly suggests that several factor pairs were involved. The parent-progeny correlation between puncture values of 34  $F_2$  plants and the mean of their  $F_3$  progeny was .64, a highly significant coefficient.

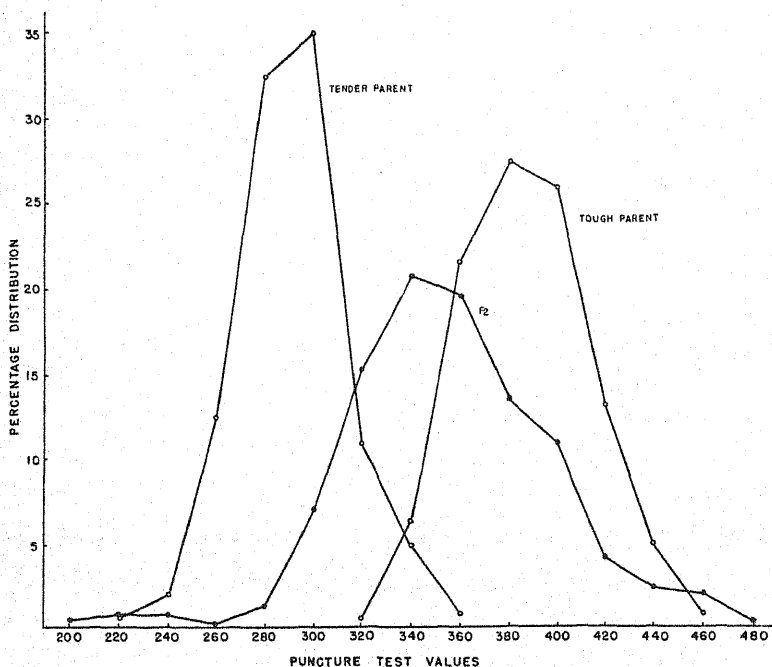


FIG. 1.—Percentage distribution of the two parents and the  $F_2$  population from a cross between a tender pericarp variety and a tough pericarp inbred line, 1937.

In the first year selfed progenies of backcrosses to the tender pericarp parent, a smaller percentage of lines with a coefficient of variability of from 5 to 8 were recovered as would be expected on the basis of the coefficient of variability of the H parent. The occurrence of relatively homozygous lines having a mean puncture test value greater than the tender parent again suggests that several factor pairs are concerned in the inheritance of pericarp tenderness.

From the first selfed progenies of the first backcross to H there were 16 progenies out of 42 with means puncture test values as low as the rows of the H parent. Two of these rows were more variable than H as determined by the coefficient of variability grouping. None of the 42 progenies gave means as high as the seven rows of the tough parent. These data indicate that tender pericarp lines may be obtained relatively easily after backcrossing. The difficulty of determining how many factors are involved is due partially to the lack of homozygosity of the H parent.



TABLE 2.—Frequency distribution of means for individual rows of parent lines,  $F_3$  progenies, from first year selfed progenies from first backcrosses to the tender pericarp parent classified according to variability as expressed by the coefficient of variation, 1937.

Culture	C.V.	Average puncture test values								
		260	280	300	320	340	360	380	400	Total
1-30 parent.....	5-8	—	—	—	—	—	—	5	2	7
H parent.....	5-8	—	1	2	—	—	—	—	—	3
H parent.....	9-12	—	1	3	—	—	—	—	—	4
Total.....		—	2	5	—	—	—	—	—	7
(1 × H) $F_2$ parent ears...	—	—	—	5	14	6	6	3	—	34
(1 × H) $F_3$ lines.....	5-8	—	—	—	1	1	5	4	1	12
(1 × H) $F_3$ lines.....	9-12	—	—	—	3	2	7	4	4	20
(1 × H) $F_3$ lines.....	13-16	—	—	1	1	—	—	—	—	2
Total.....		—	—	1	5	3	12	8	5	34
(1 × H) × H parent ears...	—	2	12	15	9	4	—	—	—	42
(1 × H) × H first year selfed.....	5-8	—	—	1	2	1	2	—	—	6
(1 × H) × H first year selfed.....	9-12	—	2	11	9	6	3	—	—	31
(1 × H) × H first year selfed.....	13-16	—	—	1	1	1	—	—	—	3
(1 × H) × H first year selfed.....	17-20	—	—	1	1	—	—	—	—	2
Total.....		—	2	14	13	8	5	—	—	42

The parent-progeny correlation between puncture values of the 42 first backcrossed plants and their first year selfed progenies was .56.

#### BREEDING FOR PERICARP TENDERNESS

From the regular breeding studies for pericarp tenderness conducted at University Farm, a typical example will be presented to illustrate the effect of selection for pericarp tenderness in a series of backcrosses to the tough parent. This backcross was planned for the purpose of improving the pericarp tenderness of the Crosby inbred line 1-30 without greatly modifying its proved combining ability. Other backcrosses have been selected also to show the recovery of the genotype of the tender parent in a cross made for the purpose of transferring the gene for yellow endosperm from a Golden Bantam inbred line, culture 78, to the tender H strain.

A summary of puncture test values of the parents, three backcrossed generations to the tough pericarp parent, and two backcrossed generations to the tender parent is given in Table 3. It is evident that selection for tenderness in a backcross to the tough parent has been effective during two generations in maintaining a heterozygous population comparable in distribution to the first segregating backcross. The backcrosses of  $(1 \times H)_1$ ,  $(1 \times H)_2$ , and  $(1 \times H)_3$  are all remarkably similar not only in their frequency distribution and means but also in the magnitude of their coefficient of variation, indicating that the

same relative level of heterozygosity has been maintained throughout three generations when the backcrosses were made to the tough parent. The  $(1xH)_{12}$  backcross in 1936 represents a sample of the progeny from 24 ears of  $(1xH)_1$  pollinated with 1-30. These backcrossed ears, selected for planting, ranged in puncture test value from 277 to 320. Similarly, the  $(1xH)_{13}$  backcross in 1937 was obtained from the progeny of 41 ears of the  $(1xH)_{12}$  population pollinated again with 1-30 and selected from the tender pericarp ears ranging from 283 to 332. The distribution of the backcrossed progenies show a fairly high percentage of individuals more tender than the 1-30 parent. These tender pericarp ears apparently have essentially the same genotype as the  $F_1$  cross as shown by the nature of their comparable segregation when crossed to the tough pericarp parent. The results from this backcross study would therefore indicate that the inheritance of pericarp tenderness in sweet corn is sufficiently simple so that extremely tender strains may be used successfully in backcrosses as a means of improving tough pericarp inbred lines that have other desirable characters. The populations used in these studies have been sufficiently small so that it has been possible to conduct several backcrosses during a single season. At University Farm in 1937, approximately 1,500 ears were puncture tested on the plant among the eight backcrosses and parents used in the program of breeding for pericarp tenderness.

In the backcrosses made to the tender pericarp H parent the data in Table 3 show a rapid recovery of the genotype for tenderness. In the first segregating backcross of  $(78xH)H$  in 1936 the mean value of the population as well as the coefficient of variability is greater than the recurrent parent. The second backcrossed population,  $(78xH)H_2$ , was obtained from ears in the former generation which were as tender as the H parent. Consequently, since they were backcrossed to the tender pericarp parent, it would be expected that the distribution in 1937 would be essentially the same as the recurrent parent. The results obtained in the second backcross show a very close agreement with expectation. The actual mean and the coefficient of variability of the second backcrossed progenies are only slightly higher than that of the tender parent, indicating nearly a complete recovery of its genotype in two backcrossed generations when selection for tenderness was practiced.

#### RELATION OF PUNCTURE TEST VALUES TO STAGE OF MATURITY AND AGE OF UNPOLLINATED SILKS

As previously indicated, a constant period of time was selected between pollination and puncture testing. A period of 20 days was chosen because under average conditions in Minnesota with the types of sweet corn grown the material has reached the optimum stage of maturity for canning. On the average, sweet corn kernels contain approximately 70% moisture 20 days after pollination—a moisture percentage considered by canning companies to be nearly optimum for a high-quality canned product.

In 1936 a study was made to determine the daily rate of change in puncture test values beginning at 18 days and extending to 22 days

TABLE 3.—Frequency distribution of puncture test values of ears from backcrosses to the tough pericarp parent and backcrosses to the tender pericarp parent with selection for tenderness.

Culture	Year	Puncture test values										Total	Mean	C. V.
		240	260	280	300	320	340	360	380	400	420			
(1×H) I <sub>1</sub> .....	1935	—	—	4	12	23	23	15	4	1	—	82	332	7.8
(1×H) I <sub>2</sub> .....	1936	—	—	5	14	36	40	26	13	2	—	136	337	7.7
(1×H) I <sub>3</sub> .....	1937	—	—	2	28	43	65	40	15	6	—	199	338	7.6
I-30 parent.....	1935	—	—	—	—	—	—	11	40	37	4	92	387	3.9
I-30 parent.....	1936	—	—	—	—	—	—	11	46	43	—	100	386	3.4
I-30 parent.....	1937	—	—	—	—	—	2	16	8	—	—	26	365	3.2
H—parent.....	1936	14	28	33	6	1	—	—	—	—	—	82	268	6.7
H—parent.....	1937	1	19	16	10	2	—	—	—	—	—	48	277	6.6
(78×H) H <sub>1</sub> .....	1936	3	17	27	22	9	3	—	—	—	—	81	286	8.0
(78×H) H <sub>2</sub> .....	1937	1	40	37	21	8	0	1	—	—	—	108	280	7.4
78 parent.....	1936	—	—	1	7	—	—	—	—	—	—	8	298	2.4
78 parent.....	1937	—	—	—	6	18	5	1	—	—	—	30	321	4.5

after pollination. Two Golden Bantam single crosses were used, Minhybrid 202, a relatively early hybrid, and Minhybrid 201, a somewhat later cross. This study was made by selecting 25 plants of a uniform stage of maturity for each variety and puncture testing these ears daily starting 18 days after pollination. Since the same ears were

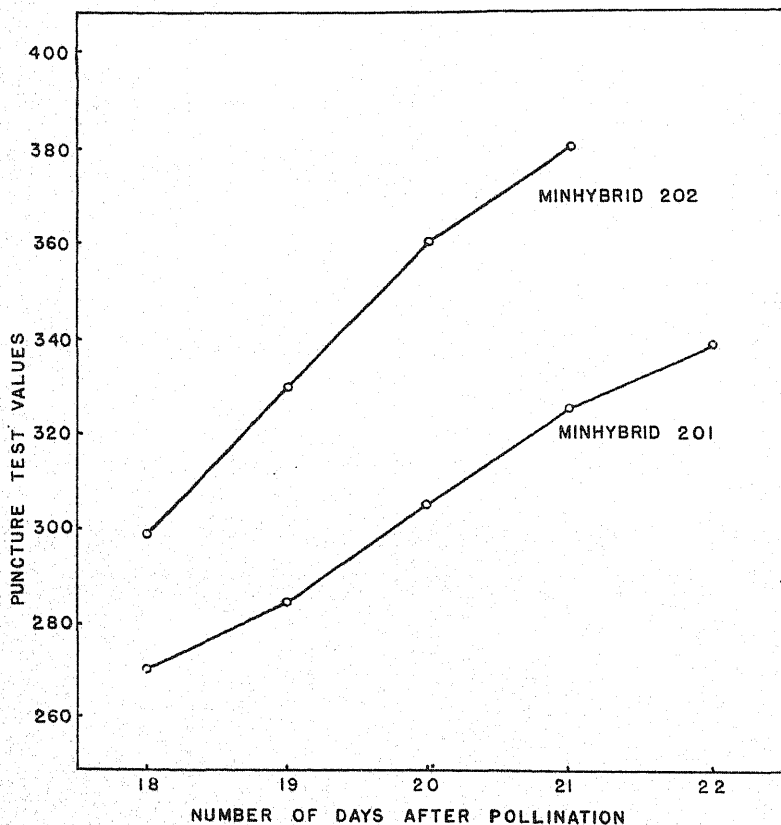


FIG. 2.—Rate of daily change in puncture test values in relation to the number of days after pollination.

used each day, the differences obtained should be due chiefly to progressive changes in pericarp toughness. In making the puncture tests on the plant, only a small portion of the husk was stripped back to expose the kernels. The husks were carefully replaced after the puncture readings had been obtained and the ears covered with a parchment bag to prevent premature loss in moisture. The study with Minhybrid 202 was terminated after the 21st day because the values for some ears were near the maximum that could be obtained with the tester used.

The results of this study, shown in Fig. 2, emphasize the importance of making all puncture test readings for a given population at

the same interval of time after pollination. The daily rate of change for Minhybrid 202 from 18 to 20 days after pollination was about 30 units and for Minhybrid 201 approximately 20 units from the 18th to the 21st day. Both hybrids tend to show a smaller daily change for the last day in which values were obtained. Minhybrid 201, the later maturing cross, also had a consistently smaller daily change than Minhybrid 202.

During the progress of these studies it was apparent that factors other than the number of days after pollination influenced the puncture test values obtained. Within the inbred lines, for example, some ears appeared to be relatively more mature than others at the same number of days after pollination. In the pollination technic employed prior to 1937, crosses or selfs were made every two or three days within a given population until the desired number of selfed ears had been obtained. By this method the silks of some ears may have appeared three days and others only one day prior to pollination. A study was made, therefore, to determine if any relationship might exist between the age of the silks at pollination time and the puncture test value. In Minhybrid 202 a fairly large number of ears were bagged and the date of silk emergence recorded for each plant. Pollinations by hand were then made on three groups of 20 to 25 plants each. In one group the silks had emerged five days prior to pollination, in another group three days, and in the third group pollination was made on the day the silks emerged. All pollinations were made for the three groups on the same day and puncture test values obtained 20 days later. The results, shown in Fig. 3, indicate clearly that the puncture test values may be greatly modified by the age of the silks at the time of pollination. These results would indicate that the pericarp tissue may develop for a period of at least five days without fertilization.

#### SUMMARY

1. In a study of the inheritance of pericarp tenderness in sweet corn, data were obtained from a cross between a very tender, open-pollinated variety and a tough pericarp Crosby inbred line. The two parents used in the cross showed a consistent difference of approximately 100 units as measured with a puncture tester, while the  $F_1$  cross between the tender and tough parents was approximately intermediate in puncture test value and also in its coefficient of variability.

2. In studies of the  $F_2$  carried on in 1935 and 1936 with populations of 79 and 136, respectively, segregation occurred with a coefficient of variability greater than that of the  $F_1$  and the H parent. In 1937, from a population of 430  $F_2$  plants in comparison with 390 of the tender pericarp and 299 of the tough pericarp parent, the  $F_2$  slightly exceeded the range of the tender pericarp parent in tenderness and of the tough pericarp parent in toughness.

3. In a study of  $F_3$  progeny rows and in first year selfed lines from backcrosses to the tender parent, lines were obtained with as low a coefficient of variations as the inbred, tough pericarp parent. The recovery of relatively pure lines having an average puncture test value in the classes intermediate between the parents suggests that sev-

eral factor pairs condition pericarp tenderness. There was only one line in  $F_3$  out of 34 with as low a mean as that of the H parent. Sixteen of 42 first year selfed lines from the first backcross gave as low means as obtained from the rows of the tender pericarp parent.

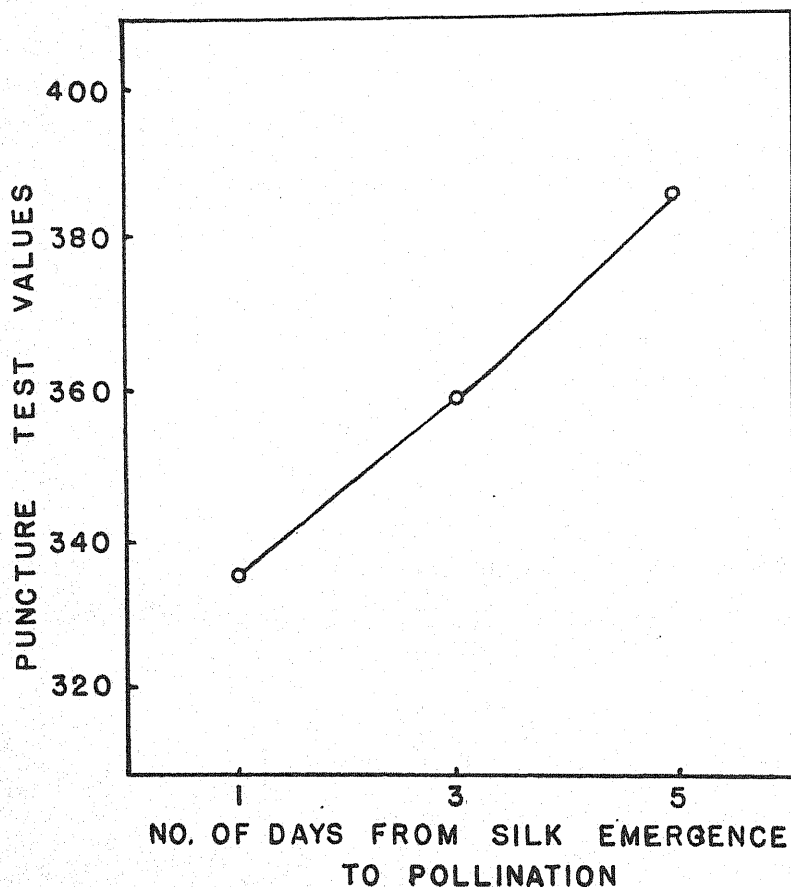


FIG. 3.—Relation between the age of silks at time of pollination and puncture test value.

4. In backcrosses to the tough pericarp parent, selection for tenderness during two segregating generations has maintained the same range in distribution of puncture test values as that obtained when the  $F_1$  was backcrossed to the tough parent. These results indicate that the genes for pericarp tenderness from the tender parent have been successfully carried in a heterozygous condition.

5. In backcrosses to the tender pericarp parent, selection for tenderness has apparently been effective in an almost complete recovery of the genotype of the tender parent in the second backcrossed generation.

6. In a study made to determine the daily changes in puncture test values from the period 18 to 22 days after pollination, a daily increase of approximately 30 units was obtained in one cross and 20 units in a later maturing hybrid.

7. Puncture test values from ears pollinated when the silks had been emerged for 1, 3, and 5 days showed an increase of over 20 units in puncture test for each interval of two days after the silks had emerged. These results indicate that the pericarp in sweet corn continues to develop without fertilization for a period of at least five days.



## THE ABSORPTION AND UTILIZATION OF NITRATE NITROGEN DURING VEGETATIVE GROWTH BY ILLINOIS HIGH PROTEIN AND ILLINOIS LOW PROTEIN CORN<sup>1</sup>

IRWIN R. HOENER and E. E. DeTURK<sup>2</sup>

IN 1896 the Illinois Agricultural Experiment Station began a series of experiments to determine whether the chemical composition of corn could be altered by selection (20).<sup>3</sup> A variety known as Burr's White was used as the foundation stock and selections were made, based upon chemical analysis, for high protein<sup>4</sup> and low protein content of the grain at maturity. These two strains have since been termed Illinois High Protein and Illinois Low Protein. They have undergone 40 generations of continuous selection.<sup>5</sup>

Beginning with a mean protein content in the grain of 10.92% in 1896, a comparatively wide spread has been attained between them. For instance, the mean values for the high protein strain the past 3 years were, respectively, 23.70, 17.71, and 21.63%, and for the low protein strain, 10.75, 5.90, and 8.01%. Fig. 1 shows the mean protein content of the grain year by year and also the highest and lowest variant among the individual ears analyzed of each line. Every year since 1921 the lowest high-protein variant has been higher than the highest low-protein variant, that is, they have never crossed.

The purpose of the investigation reported in this paper was to determine the effect of the nitrate nitrogen concentration in the culture medium upon nitrogen absorption and assimilation during vegetative growth of plants of the high- and low-protein strains, separating the total nitrogen of these plants into the various groups of compounds which are concerned in nitrogen metabolism.

The literature contains accounts of many studies which relate, to some extent, to the object of this investigation. The effectiveness of a breeding program to modify the chemical composition of corn has been demonstrated (14, 18, 19, 35, 36). Many studies (1, 2, 4, 5, 8, 11, 15, 23, 32, 33) have furnished interesting observations on the nitrogen metabolism of plants. Several workers (3, 6, 16, 21, 22, 26, 27, 31) have demonstrated the effect of environment on composition as well as on growth, and some recent papers (9, 10, 28) report on conditions which affect the assimilation of ammonium and nitrate ions. In none of the investigations referred to was there available plant material with a definite hereditary difference in nitrogen content among plants within the same species. An opportunity to observe differences in

<sup>1</sup>Contribution from the Department of Agronomy, Illinois Agricultural Experiment Station, Urbana, Ill. Published with the approval of the Director. Also presented at the annual meeting of the Society held in Chicago, Ill., December 1 to 3, 1937. Received for publication December 11, 1937.

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<sup>3</sup>Figures in parenthesis refer to "Literature Cited," p. 242.

<sup>4</sup>The term "protein" in this instance refers to the total nitrogen multiplied by the conventional factor 6.25.

<sup>5</sup>Acknowledgment is accorded to Dr. Louie H. Smith, who conducted this investigation during the first 25 years.

nitrogen utilization by such plants, was provided by Illinois High Protein and Illinois Low Protein strains of corn.

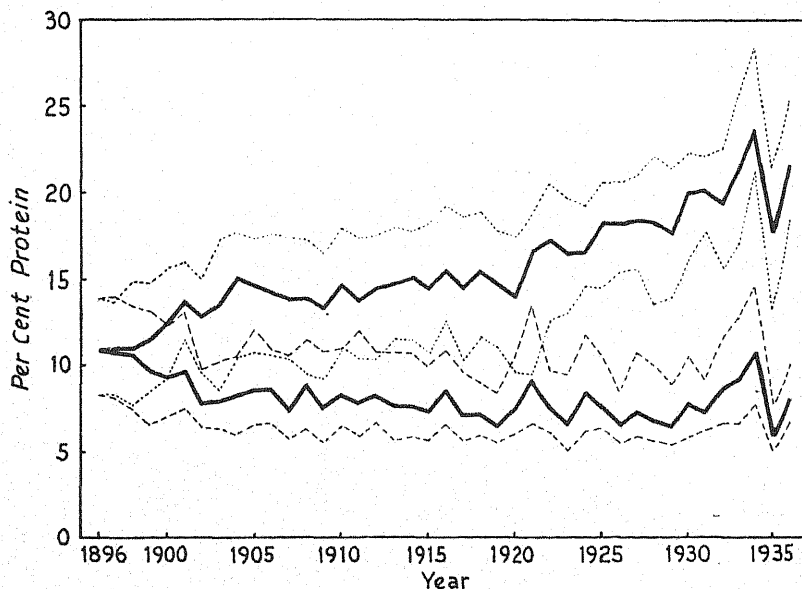


FIG. 1.—Mean yearly protein content of Illinois High and Low Protein corn, with lowest and highest variant of each line. (Courtesy Dr. C. M. Woodworth.)

## MATERIALS AND METHODS

### CONDUCT OF PLANT CULTURES

Plants of the two strains were grown in water culture at different levels of nitrogen feeding, the nitrogen being supplied as sodium nitrate. Entire plants when 50 and 88 days old were harvested and subjected to chemical analysis.

Details of the procedure were as follows: From the 1935 crop, seeds from one ear of each strain, supplied by Doctor C. M. Woodworth, were used. They contained, respectively, 19.35 and 5.45% protein. The seeds were germinated in a sterilized rag doll and were transplanted when five days old to 1-gallon glazed stoneware jars containing nutrient solution. The seedlings were held in position by round covers of wood through which 1-inch holes had been drilled, the plants being held in place by small wads of non-absorbent cotton. The culture solution was replaced three times each week. Iron was given for a 24-hour period once a week by applying on Monday the complete solution minus phosphorus and magnesium, but containing iron as  $\text{FeCl}_3$ . On Tuesday and Friday the complete solution minus iron was applied. Only the nitrogen concentrations were varied. Four nitrogen levels were maintained, namely, 25, 50, 100, and 200 p.p.m.

The stock solutions were maintained in 11-liter bottles from which aliquots were taken and diluted with distilled water to give a culture solution of the composition shown in Table 1.

TABLE I.—*Composition of culture solution.*

Element	Salt used	P.p.m. of element in final dilution
Stock Bottle 1		
Ca.....	CaCl <sub>2</sub> ·2H <sub>2</sub> O	50.0
Mn.....	MnCl <sub>2</sub> ·4H <sub>2</sub> O	1.0
Cu.....	CuCl <sub>2</sub> ·2H <sub>2</sub> O	0.5
Zn.....	ZnCl <sub>2</sub>	0.5
B.....	H <sub>3</sub> BO <sub>3</sub>	0.5
K.....	KCl	140.0
Stock Bottle 2		
P.....	NaH <sub>2</sub> PO <sub>4</sub> ·H <sub>2</sub> O	28.0
Mg.....	MgSO <sub>4</sub> ·7H <sub>2</sub> O	48.0
Stock Bottle 3		
Fe.....	FeCl <sub>3</sub> ·6H <sub>2</sub> O	20.0
Stock Bottle 4		
NO <sub>3</sub> .....	NaNO <sub>3</sub>	Varied

The pH of the solution varied from 6.3 to 6.6 and was maintained at this level. Evidence of Clark and Shive (9, 10) and of Tiedjens (32) indicates that absorption and assimilation of nitrate ions are not greatly affected by the reaction of the culture solution.

Six seedlings were planted in each jar and the stand maintained by transplanting plants carried in extra jars during the first 10 days. Greenhouse lights were used on alternate nights. Plant growth was satisfactory and the plants appeared normal.

#### SAMPLING AND PREPARATION FOR ANALYSIS

Samples were taken 50 and 88 days after planting. It was desired to harvest the plants before the vegetative development was affected by fruiting. A few plants tasseled before the final sampling and they were discarded.

The preservation of plant tissue for subsequent analyses presented a problem for which no fully satisfactory working method was found. Experiments by Vickery, Pucher, and Clark (34), indicate that the use of hot water is of doubtful validity because of the possibility of hydrolysis of glutamine and consequent liberation of ammonia. The use of cold water did not give complete extraction and was not practicable because of its inability to prevent enzymatic action. Freezing of the tissue was eliminated because of lack of facilities. Link and Schulz (24) obtained decreases in amount of soluble nitrogen when corn leaves were dried at various temperatures. Low temperatures of 32° to 45° C allowed proteolytic decomposition to take place, but no effect of the various temperatures on the total nitrogen content of the tissue was observed.

Inasmuch as the various nitrogenous components of the corn plant were desired unchanged it was concluded that hot water extraction offered the best available possibility with the least error. The method finally used, which is given in the following paragraph, is founded upon work of Chibnall (7) who showed the possibility of essentially quantitative expression of the vacuole content of cells after cytolysis with ether. Grover and Chibnall (17) showed also that the likelihood of a significant production of ammonia from the enzymatic decomposition of amides during the brief process is remote.

The whole sample of six plants including roots and tops was harvested, weighed fresh, and finely cut and mixed in a Hobart salad cutter. A small portion was taken for moisture determination and the remainder immediately covered with ether. After 30 minutes at which time the tissue was entirely flaccid, 150 ml. of distilled water were added and the ether immediately evaporated on the steam bath. The water was stirred thoroughly with the plant tissue and decanted through a linen filter. Extraction and decantation with succeeding portions of hot distilled water were continued until no appreciable test for nitrates was obtained with diphenylamine.

The water extract was evaporated to somewhat less than 500 ml. on a steam bath (85° to 90° C) and then centrifuged in a whirling type centrifuge to remove chlorophyll, protein material coagulated by heating, and any solid material which may have passed through the linen filter. The water extract was made up to 500 ml., 1.0 ml. of chloroform added, and was then ready for chemical analyses. The solid portion remaining after centrifuging was combined with the extracted residue, dried in the electric oven at 100° C and set aside for chemical analysis. All chemical analyses given are on the water extract, plant residue, or the portion of original plant tissue used for moisture determination.

#### ANALYTICAL METHODS

It was considered desirable to determine not only the total nitrogen of the plant material, but also various inorganic and organic fractions which may represent stages in protein metabolism.

*Total nitrogen.*—Total nitrogen, including that from nitrates, was determined on a portion of the dried tissue by the official Kjeldahl method modified to include the nitrogen of nitrates (25).

*Water-insoluble nitrogen.*—Water-insoluble nitrogen was determined by the Kjeldahl-Gunning-Arnold method (25) on a portion of the plant residue after water extraction.

*Water-soluble nitrogen.*—Total nitrogen in the water extract was determined by the iron powder reduction method of Pucher, Leavenworth, and Vickery (30). Free ammonia, amide, and nitrate nitrogen (13) were successively determined on a second aliquot of the water extract, after which the residue from these determinations was subjected to nitrogen determination by the Kjeldahl-Gunning-Arnold method. The detailed procedures used in these determinations will be published elsewhere.

*Total inorganic nitrogen.*—Total inorganic nitrogen was calculated by combining the nitrate and ammonium nitrogen.

*Soluble organic nitrogen.*—Soluble organic nitrogen was calculated as the difference between the total soluble nitrogen and total inorganic nitrogen and should consist chiefly of amino and amide nitrogen and secondary protein derivatives.

*Residual water-soluble nitrogen.*—No determinations of amino nitrogen were made. The residual nitrogen of the water extract, after removal of ammonia, amides, and nitrates is believed to consist chiefly of amino nitrogen and secondary protein derivatives. It was determined by the Kjeldahl-Gunning-Arnold method on the residue after the determination of ammonia, amide, and nitrate nitrogen, and it was also calculated by subtracting the sum of the above three fractions from the total nitrogen in the water extract as previously determined.

*Moisture.*—Moisture was determined by drying a portion of the original sample, after cutting and thoroughly mixing, at 100° to 101° C in an electric oven.

## EXPERIMENTAL RESULTS

## GROWTH OF PLANTS

During the first few weeks the plants of the high protein strain were noticeably darker green in color than those of the low protein strain, regardless of cultural conditions. This difference disappeared about 4 weeks after planting. All plants at the final sampling were dark green in color and normal in appearance. Green and dry weights of the 88-day-old plants are given in Table 2. The average dry weights of the low and high protein plants were 2.45 and 2.77 grams per plant, respectively. The high protein plants made greater growth at 100 and 200 p.p.m. of nitrogen than with 25 or 50 p.p.m. The low protein plants were approximately the same weight at 25, 50, and 100 p.p.m. of nitrogen and showed an increase at 200 p.p.m. Both strains at the 200 p.p.m. concentration were still growing actively when sampled.

TABLE 2.—Average green and dry weights per plant when sampled (88 days).

Nitrate nitrogen, p.p.m.	Green weight, grams*		Dry weight, grams*	
	Low protein	High protein	Low protein	High protein
25.....	26.7	23.1	2.32	2.02
50.....	24.8	25.8	2.19	2.27
100.....	25.2	36.7	2.23	3.13
200.....	34.2	42.9	3.08	3.76

\*Per plant.

## CHEMICAL COMPOSITION OF PLANTS

The following discussion is confined to the study of the 88-day-old plants. The results of the analyses of the younger plants showed similar trends. In discussing the analytical results the total nitrogen and the various groups of nitrogenous constituents will be considered separately. For convenience in studying the data, however, they are brought together in the same table. These values, expressed as percentage of the dry tissue and as milligrams of nitrogen per plant, are presented in Table 3.

*Total nitrogen.*—The two strains differed greatly in behavior as to nitrogen absorption at the different nitrogen-feeding levels. At both the lower levels, 25 and 50 p.p.m., the two strains were about equal in total nitrogen content, varying around 75 milligrams per plant (Table 3). At 100 p.p.m. the low protein strain remained unchanged while the high protein strain doubled its nitrogen content, containing 159 milligrams per plant. With a still further increase to 200 p.p.m. in the cultures, the high protein strain failed to absorb appreciably more nitrogen, but the low protein strain made a significant gain to 114 milligrams per plant. These differences are much greater than are accounted for by the increased plant growth as is shown by the percentage data in Table 3.

*Water-insoluble nitrogen.*—Water-insoluble nitrogen made up 50% or more of the total nitrogen present, except at 100 and 200 p.p.m. in the high protein strain. The higher proportions occurred at the



lower nitrogen-feeding levels (Fig. 2). This indicates an increasingly complete conversion into proteins with restriction of the available supply. Water-insoluble nitrogen followed exactly the same trend as total nitrogen. That is, the high protein strain made a large gain at 100 p.p.m., while the low protein strain showed no change until the 200 p.p.m. feeding level was reached.

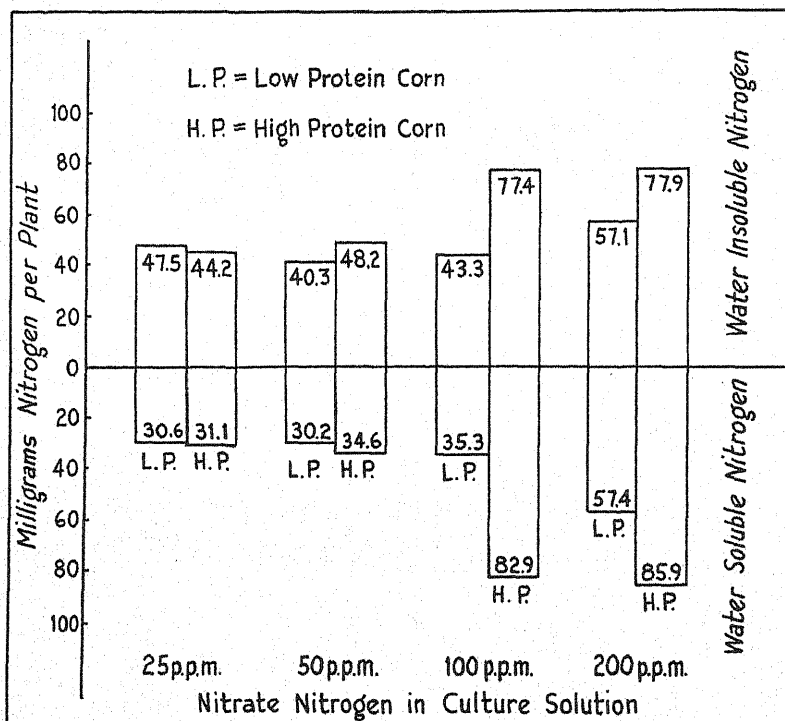


FIG. 2.—Total nitrogen (milligrams per plant) and its separation into water-insoluble and water-soluble portions.

*Water-soluble nitrogen.*—Plant analyses revealed a similar situation in the total water-soluble nitrogen as was shown for the water-insoluble portion. The high protein strain made its largest gain at 100 p.p.m. of nitrate nitrogen, while the low protein strain gained in this constituent only when the nitrogen fed was further increased to 200 p.p.m. (Figs. 2 and 3). But upon breaking this fraction down it was found that not all the water-soluble constituents follow this trend. The components of the water-soluble fraction are shown in Fig. 3.

*Nitrate nitrogen.*—Nitrates were accumulated in comparatively large amounts at the two higher feeding levels in the high protein plants, but only at the highest (200 p.p.m.) level in the low protein plants. At 200 p.p.m. the low protein plants had the same nitrate content as had the high protein plants at 100 p.p.m. (Fig. 3).



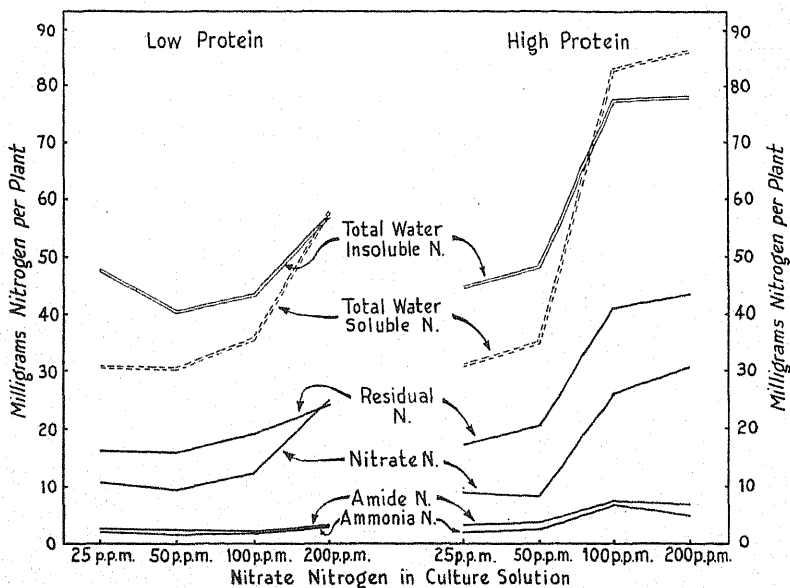


FIG. 3.—Nitrogen fractions in plant tissue, plants 88 days old.

*Ammonia nitrogen.*—The low concentrations of ammonia nitrogen throughout, support the commonly accepted view that ammonia is a transition compound which is converted to other forms almost as fast as it is produced.

*Amide nitrogen.*—Amides, like ammonia, appear to be transient forms but accumulate in slightly larger amounts than does ammonia in the high protein strain.

*Residual water-soluble nitrogen.*—This fraction, embracing as it does the immediate precursors of the proteins, is a good index of relative synthesizing ability of the plants. The superiority of the high protein strain is shown by its high accumulation of these materials at the two higher feeding levels *in addition* to its production of excessive amounts of the proteins themselves.

## DISCUSSION

Throughout the 40 years of the development of these two strains of corn they were grown on productive soil of moderately high, but not excessive, nitrate-producing capacity. It is a striking fact that in these cultures the widest difference in nitrogen absorption and assimilation also occurred in the cultures of moderate, but not excessive, nitrate-supplying capacity (100 p.p.m.). Increasing or decreasing the nitrogen supplied has been shown to narrow the difference in total and protein nitrogen as well as in other nitrogen fractions during vegetative growth. Whether or not the protein in the grain at maturity will be similarly equalized by very high or very low nitrogen feeding is still to be determined.

The differential absorption of nitrates suggests the possibility of a "resistance mechanism" to absorption. This resistance is lower in the high protein strain, being overcome by an external concentration of 100 p.p.m., of nitrate at which concentration abundant intake occurs. But in the low protein strain the resistance is much greater, being above 100 p.p.m., since it was only in the 200-p.p.m., culture that nitrate absorption occurred in more than minimal quantity (Fig. 3).

#### NITROGEN ASSIMILATION

The toxicity of the ammonia ion to most plants is fairly well established and a detoxifying agent is probably present. Prianischnikov (29) considers the formation of asparagine to be for the purpose of detoxicating ammonia in plants and to be comparable to the formation of urea in animals. With increased amounts of ammonia in this study there was a parallel increase in amount of amide nitrogen (Fig. 3). Further evidence of ammonia detoxication by amides was afforded by a concurrent series of ammonia cultures, in which nitrogen was supplied as  $(\text{NH}_4)_2\text{SO}_4$  at 25, 50, and 75 p.p.m. In no case did the ammonia nitrogen in the tissues rise as high as the maximum in the nitrate cultures, although the amide nitrogen was consistently more than twice as high as in the nitrate cultures. Evidence obtained in the ammonia cultures indicated that significant amounts of ammonium ion were absorbed and utilized in growth. The 75-p.p.m., cultures were started at 100 p.p.m., of ammonia nitrogen, but severe toxic symptoms necessitated early reduction of the concentration to 75 p.p.m.

Returning now to the nitrate cultures, the high protein plants at 100 and 200 p.p.m. contained more ammonia and amide nitrogen than the corresponding low protein plants. The high ammonia and amide nitrogen in these plants suggests that they have more adequate facilities (enzymatic activity) for reducing nitrates to ammonia than do the low protein plants. Then, so long as the nitrate supply is limited, both strains use up the ammonia and amides for forming other nitrogenous compounds as fast as they can be produced from the low nitrate supply. But at high nitrate feeding levels reductase activity goes so rapidly in the high protein plants that the ammonia and amides cannot be used up as fast as they are formed and they accumulate. The low protein plants, on the other hand, with less reducing capacity, can only produce ammonia and amides about as fast as these compounds are transformed into protein, so that no accumulation occurs. One might argue, if this is true, that nitrates should then accumulate in the low protein plants instead of ammonia and amides, and that is just what happened as soon as the threshold resistance to nitrate absorption was exceeded.

Under the conditions of greatest differentiation in nitrogen composition between the two strains of corn, namely, when grown with an adequate but not excessive nitrate supply, the high protein strain, as compared to the low protein strain, has been found to contain significantly larger quantities of all the nitrogenous constituents studied. These substances include, in addition to unassimilated nitrates, insoluble proteins undoubtedly fixed as protoplasmic material and transi-

tion products. Such a finding points to a generally more vigorous metabolic activity in the high protein strain. Whether grain formation in the reproductive stage takes place exclusively at the expense of the soluble and quickly mobile nitrogenous constituents accumulated in the vegetative tissue, or whether, on the other hand, the more complex, insoluble protein in the protoplasm of vegetative cells is rehydrolyzed and moved into the ear to contribute to grain formation is debatable. The final answer to this question will require further comparative study of the two strains at stages up to maturity.

### SIGNIFICANCE OF RESULTS

Evidence has been obtained which indicates that inheritable characteristics developed under a given nutritional environment do not necessarily find expression, at least to the same extent quantitatively, when placed under different nutritional conditions. This is not new. Five years ago one of the authors, with others (12), demonstrated a similar behavior of two single-cross corn hybrids with respect to phosphorus. On a phosphated soil one hybrid grew more rapidly, matured earlier, and yielded more corn than the other, but on a phosphorus-deficient soil no differences between the two were observable. Chemical studies of the plants explained the differences as due to different intensities of metabolic activity. Furthermore, it is commonly observed that corn varieties accommodated to soils that are poor to fair, do not on more fertile soils, compare favorably with varieties or hybrids developed on soils of high productivity.

In view of these observations it appears that it should be possible by undertaking corn breeding investigations on soils, built up to the highest possible state of fertility, to develop strains which would make 100-bushel corn yields more nearly the rule than the exception. It is probably true that such strains would not do so well on our ordinary corn-belt soils as some of the better hybrids now in existence. Nevertheless, farmers have frequently been disappointed by their corn yields on soils which are unusually high in fertility. The increasing frequency of these occurrences indicates that such "super-strains" would not be entirely without usefulness in practical agriculture.

### SUMMARY

Two strains of white dent corn which differ widely in the protein content of the mature grain when grown on relatively productive soils and which had been selected through 40 generations for high and low protein content were used for this investigation. Plants of both strains were grown in water cultures containing, respectively, 25, 50, 100, and 200 p.p.m., of nitrate nitrogen. Plant yields, total nitrogen content, and nitrogen distribution among various fractions were determined during vegetative growth.

Green and dry weights of plants increased somewhat with increasing nitrate supply.

At the two lower nitrate-feeding levels both strains contained around 75 mgm. of total nitrogen per plant. At 100 p.p.m. the low protein strain still contained the same amount, but the amount was

more than doubled in the high protein strain. With a further increase of nitrogen in the culture solution to 200 p.p.m., the low protein corn gained in nitrogen content, approaching the high protein strain, which failed to make further appreciable gain.

Of the nitrogen fractions the water-insoluble and residual water-soluble nitrogen as well as nitrates reflected the same situation as was shown for total nitrogen, thus indicating a distinct superiority of the high protein corn in assimilation as well as absorption at the 100 p.p.m., nitrogen feeding level. Its superiority tended to disappear at lower or higher feeding levels.

Ammonia and amides were low in amount in the plant tissue and varied only slightly at the different feeding levels, indicating that they are intermediate stages in protein synthesis which are used up about as fast as they are formed. Some evidence is shown that the formation of amides serves to prevent toxic concentrations of ammonia in the plant tissues.

The significance of the results is discussed with particular reference to the possibility of combining soil improvement and corn breeding studies in order to secure the benefit of the maximum combined producing capacity of both crop and soil.

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MANAGEMENT OF KANSAS BLUESTEM PASTURES<sup>1</sup>A. E. ALDOUS<sup>2</sup>

THE Kansas bluestem pasture region has an area of approximately 5 million acres. It occupies a belt varying in width from 25 to 100 miles extending north and south across the western side of the eastern third of the state. Much of this land is too broken or the soil too shallow or cherty to make its cultivation possible or advisable. The soils, however, are well adapted to the growing of the bluestem grasses. The normal annual precipitation in the region ranges from about 30 inches at the north end to approximately 36 inches on the southern end.

The vegetation was originally prairie grasses, big and little bluestems (*Andropogon furcatus* and *A. scoparius*) being the dominant species. The little bluestem was the principal species on ridge tops and the big bluestem was the dominant grass in the better land, the valleys, and on the slopes. Other grasses of secondary importance consisted of side oat grama (*Bouteloua curtipendula*), switch grass (*Panicum virgatum*), Indian grass (*Sorghastrum nutans*), and prairie June grass (*Coeleria cristata*). Kentucky bluegrass (*Poa pratense*) was increasing very rapidly until 1934, but the abnormal dry hot conditions that prevailed during that and the two succeeding summers have eliminated it. Blue grama (*Bouteloua gracilis*) and buffalo grass (*Buchloe dactyloides*) have invaded many of the pastures, occupying the ridge tops and other areas having shallow soils. There has also been a great increase during the dry years of weedy annual grasses, mainly *Hordeum pusillum* and the annual species of *Bromus*. Other grasses of secondary importance include *Schedonnardus paniculatus*, *Sporobolus cryptandrus*, *Chloris verticillata*, *Eragrostis pectinacea*, and *Sporobolus asper*.

A large percentage of the stock grazed in the bluestem region are shipped in from Texas, New Mexico, and western Kansas. The grazing season usually opens the latter part of April on commercially leased pastures and extends until about the middle of October. The season may be extended to the latter part of November during favorable years.

## GRAZING CAPACITY

There has been a steady decline in the grazing capacity of the bluestem pastures. Prior to 1900 most of the pastures were stocked at the rate of 2 acres for a cow or mature steer. The average has been gradually decreased until in 1933, or before the present dry cycle started, the best pastures were carrying one mature animal to 4 acres, while the average for the bluestem region as a whole was 5 acres per head for the summer grazing period. During the past two years the average grazing capacity has been 7 acres for a cow or a 3-year-old steer.

<sup>1</sup>Contribution No. 271, Department of Agronomy, Kansas State College, Manhattan, Kan. Also presented at the annual meeting of the Society held in Chicago, Ill., December 1 to 3, 1937. Received for publication December 9, 1937.

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The declining grazing value of the bluestem pastures led the Experiment Station of Kansas State College to initiate experiments in 1916 to obtain information on methods of utilization that would maintain the productivity of this large area of pasture land. The experiments were started on 1,400 acres of typical Flint Hill or bluestem type of pasture land located in Pottawatomie County about 10 miles north of Manhattan. The experiments were conducted in cooperation with Mr. Dan D. Casement who supplied the land and cattle. The Experiment Station built the fences, installed scales for obtaining the weights of the stock, and located and charted plots and quadrats for studying the succession of the vegetation.

In the original experiment a deferred and rotation system of grazing was compared with season-long grazing. A deferred and rotation system of grazing was practiced in three pastures, each of these pastures being protected from grazing once every three years until seed matured which in an average year was approximately September 15. This was changed after four years to a deferred system of grazing. The data obtained indicated that the bluestem grasses could maintain a normal ground cover vegetatively if properly utilized and that the production of seed was not necessary for maintaining a normal stand of grass. It was determined also that much of the grazing value of the bluestem grasses was lost after they matured and became less leafy. This was reflected in the gains made by the livestock.

The grazing experiments were discontinued at the close of the season of 1922 and were resumed the summer of 1926. Experimental results are therefore not available for the years 1923 to 1926, inclusive.

Table 1 contains the carrying capacity data for the 17 years that the experiments have been conducted. These grazing capacity data are calculated on the basis of a mature animal, either steer or cow, for a 180-day grazing period.

TABLE 1.—*Effect of method of grazing on the carrying capacity of bluestem pastures, acres per mature animal.*

Year	1916	1917	1918	1919	1920	1921	1922	1927	1928
Season-long grazing . . . .	4.79	5.24	4.64	4.73	3.67	4.10	4.55	4.59	4.28
Deferred grazing . . . . .	4.28	3.68	5.95	4.47	2.58	2.98	3.24	2.55	3.70
Year	1929	1930	1931	1932	1933	1934	1935	1936	Mean
Season-long grazing . . . .	5.99	5.44	5.66	4.84	4.84	4.97	8.32	5.16	5.04
Deferred grazing . . . . .	3.59	2.50	2.27	3.83	3.35	2.74	4.28	3.57	3.50

As previously stated, the stock were not turned in the deferred pasture until September during the first four years that the experiments were conducted. The grass, mature and stemmy at this stage of growth and rather low in palatability, was only approximately 50% utilized. Starting in 1920, the stock were turned in the deferred pasture about June 15 or when the available data indicated that the grass had made enough growth to maintain its vigor and while it was still leafy and palatable. The grazing capacity data were calculated for two pastures that were grazed the season long and for one pasture



when the grazing was deferred. One of the pastures grazed the season long had an area of 1,058 acres while the other contained 117 acres. The deferred pasture contained 111 acres. The grazing capacity of the large pasture was about 15% lower than that of the smaller pasture. This difference was due mainly to lack of water in one part of the large pasture which prevented the utilization of the forage on approximately 150 acres during a dry season.

It was found in averaging the number of pasture days obtained from the two pastures grazed the season long and comparing the result with the pasture grazed by the deferred system that approximately 30% increase in carrying capacity was obtained by the use of the deferred method of grazing. Comparing the results obtained from the two pastures of similar size, the deferred pasture carried 24% more stock than the pasture grazed the season long.

The practicability of applying a deferred system of grazing will depend upon the availability of water throughout the pasture or the cost of water development in any unit. The cost of fencing is also an important factor to be considered as is the topography and the kind and uniformity of the forage.

#### EFFECT OF METHOD OF GRAZING ON GAINS OF LIVESTOCK

Beginning with 1927, weights were taken of the livestock in the different pastures. The weights were taken at the time the stock were placed in the pastures and when they were removed. They were also weighed when they were placed in the corrals for vaccinating, marking, etc., which was about once each month. The weights were usually taken in the morning. Table 2 records the average gain per animal unit per day and Table 3 records the pounds increase or decrease per acre made by the livestock for the entire season under the two methods of grazing management.

TABLE 2.—*Gains of livestock, pounds per animal unit per day, under season-long and deferred systems of grazing, 1927 to 1936, inclusive.*

	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	Mean
Season-long grazing..	1.33	1.25	1.50	1.28	1.76	1.06	1.12	0.19	2.05	1.27	1.28
Deferred grazing..	1.34	2.17	1.77	0.80	1.95	0.85	1.31	0.09	1.31	1.32	1.29

TABLE 3.—*Gains made by livestock, pounds per acre, in pastures grazed season-long and where grazing was deferred, for the 10-year period 1927 to 1936, inclusive.*

	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	Mean
Season-long grazing..	93	70	43	42	61.5	41	58	-83	46	44	49.8
Deferred grazing..	92	86	88	57	109	46	71	6.4	55	53	66.3

The gain per animal unit per day was slightly higher for the deferred system of grazing. The difference of 0.01 pound per day is not enough to be significant. The gain per acre averaged 16.5 pounds or 33% greater for the deferred method of grazing.

The pastures were grazed by Hereford cows and calves. The calves were dropped during April and May. In the grazing capacity calculations, four April or May calves grazed until the close of the season were estimated as consuming as much forage as one cow. The increase in weight made by the livestock has been greatly reduced since 1933 owing to the abnormally dry conditions that have prevailed. The summer of 1934 was especially severe, the forage production was short and little if any increase in weight was made. The pastures were stocked with the average number of animals that they carried in previous years. This was about double the number that should have been placed on them. The number was greatly reduced in 1935 to allow the pastures to become re-established.

#### EFFECTS OF METHOD OF GRAZING ON DENSITY AND SUCCESSION OF VEGETATION

In the early spring of 1927, 25 permanent meter-square quadrats were established in pasture No. 1 or the large pasture grazed the season long, 14 in pasture No. 2 utilized by the deferred system of grazing, and 15 in pasture No. 3 grazed the season long. Four quadrats were also established in an enclosed area protected from grazing. These were established to study plant succession under natural conditions. All these quadrats were charted each June because the bluestem type of vegetation is more vigorous and uniform at this time. The average composition of each quadrat in the series for the years 1927, 1930, 1935, and 1936 is recorded in the following tables. In charting the quadrats, the position and area of each plant or group of plants was recorded on coordinate paper 1 decimeter square, or a scale of 1:10. The data for the grasses represents the average number of square centimeters per square meter on which the vegetation completely covered the ground. The data for the weeds or forbs are recorded in average number of plants per square meter. Only the more important species are listed individually in Table 4.

An analysis of these data shows a decrease in the density of the vegetation from 1927 to 1936. The decrease was greatest in the charting made in 1935. This was due to the very dry, severe condition that prevailed in 1934 and the very close grazing to which all the pastures were subjected during that summer. As previously stated the drouth was most severe on bluegrass (*Poa pratense*), although there was more than a 50% decrease in the two species of *Andropogon*, the dominant and most valuable pasture grasses in the region. Little barley (*Hordeum pusillum*) made its appearance in sufficient abundance in 1935 to be recorded in practically all the quadrats. This resulted from the reduction of the density of the perennial grasses. The quadrat data show that among the desirable grasses side oat grama was injured least, having maintained a high percentage of its original stand through the drouth, and has made a more rapid come back since 1934.

TABLE 4.—Average density of vegetation per square meter on charted quadrats.\*

Year	Af	As	Sn	Pv	Bc	Bh	Sc	Bd	Pp	Kc	Hp	Other grasses	Total grasses	Carex	Weeds	Total
Pasture No. 1																
1927.....	343	367	8	7	403	68	34	4	495	7	—	127	1,863	78	96	2,037
1930.....	318	117	169	20	230	21	13	6	227	11	—	39	1,231	92	70	1,393
1935.....	137	22	9	2	140	21	74	26	—	3	93	21	548	13	100	661
1936.....	152	27	1	4	219	29	98	44	—	—	39	15	628	22	84	734
Pasture No. 2																
1927.....	457	316	10	—	221	13	4	—	790	—	—	12	1,823	45	97	1,965
1930.....	442	216	188	30	307	7	3	3	379	18	—	13	1,623	78	94	1,795
1935.....	222	147	11	—	189	16	1	1	—	14	13	11	614	33	95	742
1936.....	240	155	2	8	203	2	43	2	—	1	14	15	686	15	60	760
Pasture No. 3																
1927.....	566	336	24	14	207	27	82	481	271	—	—	86	2,094	101	97	2,292
1930.....	441	126	78	23	246	—	20	54	315	19	—	122	1,444	121	135	1,700
1935.....	200	56	14	2	176	39	42	14	4	14	117	46	724	23	149	896
1936.....	252	59	9	4	310	32	84	4	—	1	103	39	897	21	79	996
Ungrazed																
1927.....	633	183	76	—	60	—	—	—	10	—	—	2	964	179	164	1,307
1930.....	538	201	105	—	52	—	—	—	108	—	—	18	1,022	296	57	1,348
1925.....	529	166	38	—	33	—	—	—	23	—	—	19	808	164	34	1,006
1936.....	548	316	39	—	102	—	—	—	16	—	—	—	1,021	250	40	1,311

\*Af—*Andropogon furcatus*  
 As—*Andropogon scoparius*  
 Sn—*Sorghastrum nutans*  
 Pv—*Panicum virgatum*  
 Bc—*Bouteloua curtipendula*  
 Sc—*Sporobolus cryptandrus*

Bh—*Bouteloua hirsuta*  
 Bd—*Buchloe dactyloides*  
 Pp—*Poa pratensis*  
 Kc—*Koeleria cristata*  
 Hp—*Hordeum pusillum*

All three pastures show approximately the same successional trends, there being a decrease each year until the growing season of 1935. There were a larger number of plants of little barley in pasture No. 3 than in the other two pastures. The greater number largely accounts for the increased percentage of grasses in this pasture in June 1936 over pastures Nos. 1 and 2. Sand drop seed (*Sporobolus cryptandrus*) has increased in all pastures through the drouth. This is generally true in all pastures throughout the Flint Hill region. This grass is low in palatability but will hold the soil from eroding and is readily replaced by the more desirable grasses upon the return of more favorable growing conditions.

The ungrazed areas showed a more stabilized condition with little change even after 1934. There has not been any invasion on these plots of the weedy grasses such as *Sporobolus cryptandrus* or *Hordeum pusillum* or the short grasses (*Bouteloua gracilis* or *Buchloe dactyloides*). The quadrat data for the ungrazed plots show the density of the vegetation to be equally as high in 1936 as in 1930 when the highest density was recorded. The density of the vegetation was much less for the ungrazed plots owing to the larger amount of big bluestem which makes a higher top growth. This tends to reduce tillering and spreading on the ground.

The maintenance of a somewhat normal stand of vegetation on the ungrazed plots suggests that the injury from the drouth came largely from high soil temperatures rather than lack of soil moisture. The moisture content of the ungrazed plots was no higher than the grazed, but the daily maximum temperatures of the soil at a depth of 1 inch was at least 4° F less on the plots protected from grazing. The close cropping of the grazed areas also weakened the plants making them more susceptible to injury.

#### NUTRIENT VALUE

Bluestem grasses are very palatable and nutritious in their leafy stages of growth. An indication of their nutrient value is shown in Table 5.

These data indicate that the ungrazed bluestem grasses are very nutritious and capable of producing good gains until early July. After this time they become less leafy, more stemmy, and are gradually reduced in nutritive content and palatability. The moderately grazed pasture will provide very good forage until its growth is checked by dry weather. Its value may increase in late summer and fall with reduced temperatures and normal rainfall. The quality of the bluestem grasses will be governed by the stage of maturity and their succulence. In an average year a moderately grazed bluestem pasture will provide good palatable nutritious forage through the growing season. The growing conditions will be an important factor in the quality of the forage.

An analysis of the calcium and phosphorous content of the bluestem grasses showed an adequate calcium content. They also contained enough phosphorus in the leafy stages of growth to meet the mineral requirements of livestock. The phosphorous content de-

TABLE 5.—*Protein and crude fiber content of bluestem grasses at different stages of growth from ungrazed and moderately grazed pastures.*

	May		June			July		August		September		October
	8	19	5	16	29	16	30	11	29	10	22	3
Ungrazed												
Protein, %	15.80	13.20	8.99	7.82	6.26	6.13	5.45	5.36	5.48	4.65	3.76	3.46
Crude fiber, %	26.0	28.25	31.40	31.25	32.67	33.60	36.04	34.78	33.65	33.20	33.40	34.73
Plucked from Moderately Grazed Pasture												
Protein, %	15.78	13.65	12.35	10.40	7.59	6.57	5.16	4.53	6.62	7.92	7.25	7.35
Crude fiber, %	25.92	26.13	25.99	28.95	29.22	28.94	28.93	29.23	28.31	30.10	30.22	28.44

creased as the grass matured. The calcium ranged from 0.550% in the immature stages of growth to 0.328% in the mature plants. The phosphorous content ranged from 0.300% in the grass during May to 0.100% in September when the grass was mature. Moderately grazed bluestem grass had a minimum phosphorous content of 0.198%.

In addition to the above, bluestem grasses are valuable pasture plants because they make a major portion of their growth during June and July, and if moisture is available, a substantial amount of forage will be produced during August. In contrast with this most of the "tame" perennial grasses are semi-dormant after their normal period for maturing seed or from July until late summer or early fall.

#### EFFECT OF CLIPPING ON FOOD RESERVES, YIELDS, AND SUCCESSION OF BLUESTEM GRASSES

Since it is impossible to measure accurately the effect of different grazing treatments on the growth and succession of vegetation, an effort was made to obtain these data through clipping the vegetation at different frequencies simulating, as nearly as possible, various intensities and methods of grazing. The plots were established in May 1927 in typical bluestem vegetation and the clipping was started immediately afterward.

Table 6 records the effect of the different frequencies of clipping bluestem grasses on the percentage of total starches and sugars in the roots, the yield per acre of top growth and roots, and the succession of big and little bluestem. The change in the density of big and little bluestem grasses, or succession, was recorded in square centimeters complete basal ground cover of vegetation per square meter for the years 1927 and 1933. All plots from which these data were obtained were clipped to a height of 1½ inches.

TABLE 6.—*Effect of clipping on the total percentage starches and sugars in roots, yield of forage and roots, and the change in the density of the vegetation from 1927 to 1933.*

	Un-clipped	Clipped every 14 days	Clipped every 21 days	Clipped every 14 days, July 1–Oct. 1
Starches and sugars, %.....	14.07	9.18	10.03	10.64
Yield of vegetation, lbs. green weight per acre.....	4,171	2,444	2,943	3,850
Dry weight of roots, lbs. per acre, top 7 inches of soil.....	6,703	2,705	4,233	4,928
Density of big bluestem, sq. cm. per meter 1927–33.....	750; 645	556; 47	629; 184	763; 246
Density of little bluestem, sq. cm. per meter, 1927–33.....	201; 274	338; 52	348; 92	146; 134

The total starches and sugars in the roots of the grasses, which represent the principal food reserve elements, were analyzed at the close of the 1928 grazing season. The sod was dug to a depth of 7 inches and the roots removed from the soil by washing. These data

represent the effect of clipping during two seasons. It will be noted that the total starch and sugars were very high in the unclipped grass. The amount was moderately high in the roots obtained from the plots protected until August then clipped at 2-week intervals until October or until little or no growth is made in the bluestem grasses. This indicates that the building up of the food reserves in the roots is mainly done during the beginning of the season. This agrees with grazing experiments which show that the greatest injury to bluestem grasses arises from close grazing at the beginning of the growing season and that the pastures are greatly improved by protection or lightly grazing during May and June. The plots clipped every 3 weeks, which represents rather close grazing, showed a materially reduced starch and sugar content in the roots, the amount in all probability being insufficient to promote the most vigorous growth. The plots clipped every 2 weeks, which represents very close grazing, was extremely low in food reserves. The bluestem grasses made little growth the second year on these plots and were being replaced by weedy species.

The yields of forage obtained from the clipped plots represent an average of seven years, 1927 to 1933, inclusive. They vary inversely with the frequency of clipping. The highest yield, or 4,171 pounds green weight, was obtained from the plots that were clipped at the end of the growing season. The lowest yield was obtained from the plot clipped every 2 weeks. Over 50% of the material harvested from this plot was annuals as was shown by the studies on succession. The plot clipped every 3 weeks had about one-third of its foliage during the last two years composed of annuals and weeds.

The data on the yield of roots was obtained by digging 2 square feet of sod on each plot to a depth of 7 inches. The yields represent an average of three years results, 1928 to 1930, inclusive. The yield of the roots is very closely correlated with the yield of the top growth. The yield of roots as well as the top growth decreased as the clipping treatments were extended from year to year. The root content of more closely clipped plots was composed of from 30 to 60% of annuals and weeds during the last year that the root data were obtained.

The data on the succession of the vegetation are recorded for big and little bluestem, which represented 75% of the vegetative composition at the time the first chartings were made. These data were not extended to 1934 owing to complications arising from the extreme drouth which effected all plots very severely. There was little decrease in the density of the unclipped plots. The other extreme developed in the plots clipped every 2 weeks, eliminating the two dominant grasses with the exception of scattered plants that were the remnants of vigorous clumps. The plots clipped every 3 weeks throughout the year had retained approximately a fifth of a stand, but the plants were greatly reduced in vigor. The plots clipped every 2 weeks after August 1 had retained approximately a 40% stand.

#### DISCUSSION AND CONCLUSIONS

The Kansas bluestem region has been gradually decreasing in carrying capacity, the decrease being most pronounced after extreme-



ly dry seasons. To obtain information on methods of grazing management that could be used to maintain the grazing value of this large acreage of grazing land, the Kansas Agricultural Experiment Station initiated grazing experiments in 1916. The earlier experiments of deferring grazing until after seed was mature resulted in a great waste of forage owing to the grasses being tough and unpalatable after they have completed their growth. After four years, the grazing was deferred only until about June 15 when the forage was palatable and nutritious. This period of protection every two or three years was believed to be sufficient to maintain the normal stand and vigor of vegetation.

The results of the deferred system of grazing gave an increase of approximately 25% in carrying capacity and 33% increase in the gains in pounds of livestock per acre over that obtained in the pastures grazed the season long. The desirable forage species were maintained equally as well in the deferred as in the pasture grazed the season long.

The crude protein and the mineral content of the bluestem grasses are high enough in their leafy stages of growth to provide adequately for the nutritional requirements of the livestock as well as to provide satisfactory gains in weight. Clipping experiments showed the yield of the tops and roots to be inversely proportional to the frequency of clipping. The density of the desirable grasses and their food reserves were approximately in the same proportion.

The study indicates that a deferred system of grazing may be used to obtain the highest use of the bluestem pastures with the minimum amount of injury.

The application of this system requires the additional fencing or the use of tillable land to grow supplemental pasture crops to provide forage for livestock during the early part of the grazing season when the grazing is deferred. The latter is not practical in a major part of the area because of the very small percentage of tillable land available for this purpose.

## THE RELATION OF FERTILIZERS TO THE COTTON PLANT PRODUCED IN THE BLACKLAND PRAIRIE SECTION OF TEXAS<sup>1</sup>

H. V. JORDAN, J. H. HUNTER, AND J. E. ADAMS<sup>2</sup>

CORRELATED field and laboratory studies of the relation of fertilizers, tillage, and crop residues to the yield and maturity of cotton and the incidence of cotton root-rot, have been made by the Division of Soil Fertility Investigations, Bureau of Plant Industry, U. S. Dept. of Agriculture. A report of some of the early work (4)<sup>3</sup> gave data which showed that an evasion of losses in yields due to the soil-borne fungus *Phymatotrichum omnivorum* (Shear) Duggar was accomplished to a degree by treatments which hastened the development of the plant. A reduction in the incidence of the disease was indicated for practices which tended to produce highly vegetative growth.

Susceptibility to root-rot becomes apparent in the field when the cotton plant has approximately six true leaves and is entering the fruiting stage. Planting after the normal date has been found, generally, to retard the initial appearance of the disease and to reduce losses (2, 5, 7). It is recognized that rapid early development and the production and retention of squares at the beginning of the season are factors in the earliness of the cotton crop (1, 3, 8). A prolongation of the period of rapid fruiting by nitrogen fertilizers is indicated by certain studies (8).

This report presents a limited study of the effect of fertilizers on the numbers of squares and bolls and on the heights of plants, using these as indices of development. The relation of these to the incidence of root-rot is discussed. A more complete and detailed morphological study of the relation of fertilizers to plant development is under way in cooperation with the Division of Cotton and Other Fiber Crops and Diseases, using an area uninfested by the disease.

### PLAN OF EXPERIMENT

The use of the Latin square arrangement of plats was begun in 1935 to test further a number of fertilizers found by the triangle method of study (6) to be most outstanding for investigation on the Houston and Wilson soils. Two such experiments were conducted on Wilson clay loam in 1935; one was in Hunt County, on the farm of Richard Craig, near Campbell, Texas, and the other was near Elgin, in Travis County, on the farm of Emil Kruger. The experiment on the latter farm was repeated in 1936, and a new trial was begun near Caddo Mills, in Hunt County, on the farm of H. G. Williams. One such experiment was con-

<sup>1</sup>Contribution from the Division of Soil Fertility Investigations, Bureau of Plant Industry, U. S. Dept. of Agriculture. Also presented at the annual meeting of the Society held in Chicago, Ill., December 1 to 3, 1937. Received for publication December 16, 1937.

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<sup>3</sup>Figures in parenthesis refer to "Literature Cited", p. 261.

ducted on Houston black clay in 1936 near Pflugerville, in Travis County, on the farm of Alfred Fuchs.

Fertilizers in each of the experiments included an 0-15-0, 3-9-3, 9-3-3, and 15-0-0 analysis<sup>4</sup>, and unfertilized check plats were included. Percentages dead cotton for all plats were assembled periodically in each experiment. Plant data were obtained in two experiments on the Wilson soil, namely, those on the clay loam in 1935 and on the fine sandy loam in 1936. Similar data were obtained from a single experiment on Houston black clay in 1936. All root-rot data are amenable to statistical analysis, but only in 1936 were plant data so assembled.<sup>5</sup>

The data for the Houston black clay soil, and those of the Wilson series which are lighter in texture, are treated separately due to an inherent difference in their response to fertilizers.

#### DATA FROM THE WILSON SOILS

In following the extent of the attack on plants by root-rot, it is generally more convenient to measure the footage of dead cotton than that of green cotton. An increase in the percentage of dead cotton, as the season advances, is accompanied by a like decrease in green cotton. Differences quoted in the analysis of variance necessarily represent either dead or green cotton.

Periodic records of the amounts of dead cotton for the several plats for the four experiments on the Wilson soil are presented in Table 1. The value given for a particular treatment on a given date is an average of the individual values of five or six replications. Table 2 gives the results of the analysis of variance of the data given in Table 1.

The highly significant variance between means of dates is a reflection of the progressive increase or decrease in the percentage of dead or green cotton, respectively, with the advance of season. The variance between means of treatments is also highly significant, and fertilizers have had a valid effect on the prevalence of dead cotton as shown by a comparison of fertilized and non-fertilized plats.

The all-phosphate fertilizer, 0-15-0, increased the amount of dead cotton over that on non-fertilized check plats, the difference being statistically significant. Examination of the records obtained with the 3-9-3 fertilizer on individual dates shows that in some instances this fertilizer increased mortality significantly, while in some instances there were significant reductions. Reductions occurred particularly in the case of the experiment in Hunt County in 1936. The 3-9-3 fertilizer may function either to increase or reduce root-rot. The dual behavior of this analysis is not fully understood, but it is thought to depend on seasonal conditions, rates of application, and other factors. Both high-nitrogen fertilizers caused highly significant reductions in dead cotton as compared with unfertilized check plats.

Plant and yield data from studies on Wilson clay loam in 1935 are presented in Table 3. Although the plant records were secured at

<sup>4</sup>The formulas indicate  $N-P_2O_5-K_2O$ . The nitrogen was derived in equal proportions from sulfate of ammonia and nitrate of soda. Phosphoric acid was from superphosphate and potash from sulfate of potash. The rate of application was 900 pounds per acre.

<sup>5</sup>Acknowledgment is made to N. E. Rigler, D. R. Ergle, Prinston Jenkins, and H. A. Nelson for help at various times in collecting the data.

TABLE 1.—Percentage dead cotton at successive dates in four fertilizer experiments on light-textured Wilson soils, 1935-1936.

Plat treatment	1935											
	Wilson clay loam, Hunt County						Wilson clay loam, Travis County					
	July 18	July 31	Aug. 15	Aug. 28	Sept. 30	Oct. 17	June 21	July 5	July 19	Aug. 2	Aug. 16	Oct. 4
0-15-0.....	1.0	7.1	13.8	22.8	46.6	70.0	0.4	1.9	7.7	20.2	32.0	65.6
3-9-3.....	1.3	9.7	17.1	26.3	43.6	55.3	0.4	1.7	7.4	21.8	35.8	68.1
9-3-3.....	0.6	1.5	5.1	8.1	23.7	34.7	0.1	1.6	5.6	13.4	23.1	58.1
15-0-0.....	0.5	3.5	6.3	12.9	26.4	43.3	0.1	1.2	4.0	12.0	20.6	50.3
Check.....	2.0	8.1	16.7	27.4	52.6	70.9	0.2	0.9	3.7	13.1	23.5	57.0
Mean.....	1.1	6.0	11.8	19.5	38.6	54.8	0.2	1.5	5.7	16.1	27.0	59.8
	1936											
	Wilson clay loam, Travis County						Wilson fine sandy loam, Hunt County					
	June 19	July 6	July 20	Aug. 3	July 14	July 28	Aug. 12	Oct. 7	Mean for the 2 years			
0-15-0.....	3.7	17.1	45.9	74.3	4.6	15.0	25.3	22.0	24.9			
3-9-3.....	2.7	13.4	37.4	72.6	1.5	5.4	6.8	7.1	21.8			
9-3-3.....	1.2	9.2	29.8	61.7	0.1	1.0	1.3	1.5	14.1			
15-0-0.....	0.4	4.7	17.8	46.2	0.2	0.6	1.9	2.1	12.8			
Check.....	2.4	10.1	27.6	59.5	2.4	9.3	16.5	13.7	20.9			
Mean.....	2.1	10.9	31.7	62.9	1.8	6.3	10.4	9.3				

TABLE 2.—*Analysis of variance in percentages of dead cotton as affected by fertilizers in four experiments on Wilson soils, 1935-36.*

Source of variance	Degrees of freedom	Sum of squares	Mean square	F
Between means of dates . . . . .	19	39,257.41	2,066.18	65.6*
Between means of treatments . . . .	4	2,174.09	543.52	17.3*
Error . . . . .	76	2,393.65	31.5	—
Total . . . . .	99	43,825.15		

\*Exceeds the 1% point.

Plat treatment	Average % dead cotton	Increase or decrease due to treatment
0-15-0	24.9	4.0
3-9-3	21.8	0.9
9-3-3	14.1	-6.8
15-0-0	12.8	-8.1
Check	20.9	
Minimum mean difference for significance (P=0.05) 3.5		
Minimum mean difference for significance (P=0.01) 4.7		

approximately 1-week intervals, only averages for an early vegetative and fruiting period and a later period of boll development are given. An analysis of variance was not made.

During the early period height and number of squares were increased by all fertilizers, while increases in numbers of nodes and bolls were obtained with phosphate alone and with the complete fertilizers. The least effect, where obtained, was from the all-nitrogen (15-0-0) fertilizer.

Height and numbers of squares and bolls were also greater during the late period for all fertilizer treatments. Height and number of bolls were affected most by the complete fertilizers with little difference between the two. Only small differences in the average numbers of nodes were apparent among treatments. While the 15-0-0 fertilizer produced the minimum effect on height, nodes, and bolls during both periods, it gave the greatest average number of squares during the late period at each date of record.

Increases in yield from these fertilizers ranged from 88 to 356 pounds of seed cotton per acre. A significant acceleration of maturity, as shown by increased amounts at first picking, was obtained with each fertilizer except the 15-0-0.

These plant and yield data indicate that the 0-15-0, 3-9-3, and 9-3-3 fertilizers accelerated development, while nitrogen alone did not. There was a tendency, however, for the 15-0-0 to prolong the fruiting stage as shown by the greater number of squares during the late period.

Plant data obtained on the Wilson soils in 1936 are given in Table 4. These were treated by analysis of variance for each plant character for the several dates of observation. Significant differences due to some treatments are indicated.

Accelerated development, as shown by a predominance of signifi-

TABLE 3.—*Plant and yield data from an experiment on Wilson clay loam, Travis County, 1935.*

Fertilizer Treatment	Early period, June 11 to July 9				Late period, July 16 to Aug. 6				Acre yield of seed cotton, lbs.	
	Height of plant, inches	Number of nodes	Number of squares	Number of bolls	Height of plant, inches	Number of nodes	Number of squares	Number of bolls	Total	First picking
0-15-0.....	16.7	14.4	6.9	0.5	28.1	22.1	5.0	5.0	485*	319
3-9-3.....	20.4	15.5	10.4	1.4	30.5	21.1	5.2	7.5	665*	492
9-3-3.....	19.1	15.2	8.9	0.7	30.2	21.3	5.4	7.8	740*	514
15-0-0.....	14.8	13.9	6.3	0.3	26.0	21.1	11.7	5.0	472†	257
Check.....	14.3	13.8	5.1	0.3	22.5	21.8	4.5	4.1	384	208

\*Yields are significantly larger than those of check plots ( $P=0.01$ )†Yields are significantly larger than those of check plots ( $P=0.05$ )

cant increases in height and in numbers of bolls and squares at the several dates of record, is indicated for the 0-15-0, 3-9-3, and 9-3-3 fertilizers. Although plants grown on the 15-0-0 plats differed significantly from those on the unfertilized checks in only one instance, there is a tendency for a reduction in height and of numbers of squares and bolls recorded at the earlier dates.

TABLE 4.—*Plant and yield data from an experiment on Wilson fine sandy loam, Hunt County, 1936.*

Date	Plant character	Plat treatment				
		0-15-0	3-9-3	9-3-3	15-0-0	Check
June 16	Height, inches	10.33*	10.54*	8.33*	5.85	6.66
	Number of squares	2.15*	2.65*	1.71	0.80	1.12
June 23	Height, inches	10.97*	11.65*	9.93*	6.89	7.23
	Number of squares	2.80	3.60*	2.67	1.45	1.82
June 30	Height, inches	12.53*	13.13*	11.90*	8.72	8.80
	Number of squares	2.30*	2.15*	2.27*	1.25	1.12
	Number of bolls	0.50*	0.31	0.43*	0.10	0.13
July 13	Height, inches	15.77*	17.35*	17.02*	12.69	12.70
	Number of squares	1.17*	1.28*	1.62*	0.77	0.58
	Number of bolls	1.45*	1.55*	1.43*	0.50	0.67
July 27	Height, inches	17.27*	17.77*	18.37*	15.91*	15.03
	Number of squares	1.22	0.98	1.17	1.87	1.53
	Number of bolls	2.24*	1.89*	1.76*	0.83	0.64
August 11	Height, inches	17.87*	18.12*	18.47*	15.25	14.66
	Number of bolls	2.00	2.33*	1.92	1.55	1.42
Total yield of seed cotton per acre, lbs. ....		210*	258*	202*	71	95
Bolls open August 13, %† . . . . .		52.1*	63.9*	48.8*	26.7	32.1

\*Significantly greater than corresponding character on check plats.

†Only one picking made; counts of open bolls are offered in lieu of amounts at first picking.

If the 15-0-0 plat is used for reference rather than the unfertilized check, it is of interest to note that, through June, cotton on the 0-15-0, 3-9-3, and 9-3-3 plats had significantly more squares than plants from the 15-0-0 plats. On July 13, only the complete fertilizers maintained this same relative position, while on July 27, which was the final record date, plants on the 15-0-0 plats had significantly more squares than those on plats fertilized with phosphate alone or complete ratios. Thus, a trend towards prolongation of the fruiting period by the 15-0-0 fertilizer, is shown by comparison with other fertilizer treatments, although differences are not significant when comparison is made with unfertilized checks.

The crop was virtually a failure on the unfertilized and 15-0-0 plats, due principally to drouth. The 0-15-0, 3-9-3, and 9-3-3 fertilizers, however, increased yields and hastened the opening of bolls by margins which were significant in each case. The 15-0-0 fertilizer was not effective in either of these respects.



## RESULTS ON HOUSTON BLACK CLAY

Concurrent studies of the effect of fertilizers on root-rot and plant character on Houston black clay are so far limited to a single experiment in 1936. Accordingly the data are not presented in detail.

Records of the occurrence of root-rot on the various plats were obtained on five successive dates from June 24 to October 2. Plats fertilized with the 0-15-0 fertilizer had higher percentages of dead cotton than the unfertilized check plats on the first two dates of record, namely, June 24 and July 8, the differences in each case being highly significant. The 3-9-3 fertilizer caused a significant increase in the percentage of dead plants on June 24. The high-nitrogen fertilizers were at no date effective in causing statistically important reductions in dead cotton.

The plant characters used as indices of development in these studies were recorded on June 15 and 29 and on July 13 and 27. The 3-9-3 fertilizer definitely accelerated development of the cotton, with significant increases in heights of plants and in numbers of squares through the middle of July, in comparison with the unfertilized check plats. The number of bolls showed an increase also on June 29. The effect of the 0-15-0 fertilizer was somewhat less pronounced; however, height and number of squares were increased on June 15 and height and numbers of bolls were greater on July 13. The 9-3-3 fertilizer caused an increase in number of squares on June 29 and in height of plants on July 13. Nitrogen alone (15-0-0) did not at any time have a significant effect on the plant characters studied except for a reduction in number of bolls on July 27. This field was heavily infested with insects during the latter part of the season, which may have disturbed the trend of fertilizer effects.

## DISCUSSION

On the Wilson soils there is but a partial correlation of plant development and the incidence of root-rot. There appears to be a definite acceleration of development by the 0-15-0 fertilizer and this effect is accompanied by a statistically important increase in the amount of root-rot on these plats. While there is a definite decrease in the amount of root-rot on the 15-0-0 plats, these plants show but a tendency towards a prolongation of the fruiting stage, without materially increasing yields.

The effect of the 3-9-3 ratio is to accelerate development, but its relation to root-rot is variable. A summation of the data from these plats shows that the average result is that of increasing the mortality of cotton plants. Although the summary gives an amount not of statistical importance, a study of individual records, as given in Table 1, reveals that both increases and decreases have been produced. In either case some of the differences are of statistical importance. This dual behavior is thought to be associated with seasonal conditions, rate of application of the fertilizer, and probably other factors.

The more apparent anomaly is that of the 9-3-3 fertilizer. Its effect

is to stimulate plant development to an extent comparable with that of the 3-9-3 ratio, but it reduced root-rot by a significant margin.

The 1-year study on Houston black clay shows an acceleration of development due to the 3-9-3 fertilizer and to a lesser extent to the 0-15-0 and 9-3-3 ratios, in the order named. There are associated increases in root-rot prevalence caused by the 0-15-0 and 3-9-3 ratios. Nitrogen alone was not effective in changing either the plant characters studied or percentages of dead cotton.

Visual differences in the general appearance of unfertilized plants and those grown in the field with high-nitrogen and high-phosphate fertilizers are greater than is indicated by the studies presented. When the phosphate-fed plants show decided evidence of maturity the nitrogen-fed plants retain their vegetative characteristics, with large, dark-green leaves and the continuation of fruiting. Unfertilized plants are intermediate with respect to these characters.

The soils used differ in their response to fertilizers. A ratio in which the amount of phosphate exceeds that of nitrogen is indicated for the Wilson series, while the converse is indicated for the Houston black clay. The effect of potash is more outstanding on the lighter-textured Wilson soils.

#### SUMMARY

Cotton was grown on Wilson clay loam, Wilson fine sandy loam, and Houston black clay soils, using fertilizers of 0-15-0, 3-9-3, 9-3-3, and 15-0-0 analyses. Periodic records were made of the numbers of plants killed by root-rot, of the height, and numbers of squares and bolls.

Under the conditions of the experiment, an analysis of variance for four fields located on the Wilson soil showed that the 15-0-0 and 9-3-3 fertilizers reduced the number of plants killed by root-rot and that the 0-15-0 increased the mortality by amounts of statistical importance. The 3-9-3 ratio may either increase or decrease the kill as shown by individual records, but a summation indicated an increase which was not of importance. Differences on the Houston soil were confined to the 0-15-0 and 3-9-3 ratios. For the first two dates of record the increases effected by the 0-15-0 were of importance, while that of the 3-9-3 occurred on the first date.

Phosphate alone and the complete fertilizers accelerated the development of the plant when height and numbers of squares and bolls were considered as indices; during the earlier part of the season the increases are generally of statistical importance. On the Houston soil the effect is produced by the 3-9-3, 0-15-0, and 9-3-3 fertilizers. Nitrogen alone (15-0-0) only tends to delay development.

A correlation of an acceleration of plant development and the incidence of root-rot is indicated for the 0-15-0 fertilizer. The variable relation of the complete ratios and the tendencies for the 15-0-0 ratio are discussed.

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### NOTE

#### THE CENTER OF MEMBERSHIP FOR THE AMERICAN SOCIETY OF AGRONOMY

THE geographical distribution of the members of the American Society of Agronomy is naturally one factor which should be taken into consideration in selecting the place for the annual meeting. It should be possible to determine the location of a centroid such that 100% attendance at a meeting held at this place would require a minimum number of man-miles of travel. Railroad or highway distances should, of course, be used in such a calculation, but this would complicate the problem considerably. Shortest airline distances may be approximated by expressing locations in terms of latitude and longitude.

The names and addresses of the 1,103 members of the Society within the continental United States were kindly supplied by the Secretary. Making use of maps, the latitude and longitude values for individual members were estimated to the closest tenth of a degree. Locations for a few individuals were not given on maps which were conveniently available. These individuals were arbitrarily assigned central locations in their respective states.

Because of possible usefulness in calculating regional centroids, the sum of the latitude and longitude values for the members of each state was tabulated and is submitted in Table 1. The average latitude and longitude values for the whole membership in the United States were found to be, respectively, 39.3 and 90.3 degrees. The membership centroid thus lies in the state of Illinois about 45 miles due north of St. Louis, Missouri.

No correction has been made for a small error in the longitude of the centroid arising from the fact that the number of miles along the earth's surface for 1 degree change of longitude varies with the latitude.

Since the latitude and longitude for each member of the Society has been tabulated on the membership list, it would be an easy matter to determine to what extent the place of the annual meeting effects the centroid of members attending the meeting.—L. A. RICHARDS, *Iowa State College, Ames, Iowa.*

TABLE I.—*Latitude and longitude values for members of the American Society of Agronomy by states.*

State	Number of members	Latitude	Longitude
Alabama.....	18	589.4	1,538.1
Arizona.....	11	355.7	1,223.2
Arkansas.....	10	357.3	934.0
California.....	44	1,630.7	5,317.8
Colorado.....	21	834.3	2,187.2
Connecticut.....	15	621.3	1,093.2
Delaware.....	3	119.1	227.0
District of Columbia.....	91	3,530.8	7,007.0
Florida.....	20	592.0	1,653.2
Georgia.....	19	632.1	1,589.1
Idaho.....	8	369.1	932.6
Illinois.....	48	1,940.8	4,250.5
Indiana.....	31	1,247.3	2,691.6
Iowa.....	63	2,626.9	5,896.8
Kansas.....	51	1,991.2	4,931.0
Kentucky.....	12	454.1	1,023.5
Louisiana.....	15	459.7	1,274.8
Maine.....	9	405.0	617.6
Maryland.....	19	747.5	1,461.5
Massachusetts.....	12	507.4	870.1
Michigan.....	22	939.7	1,860.2
Minnesota.....	33	1,527.1	3,161.2
Mississippi.....	15	499.4	1,336.3
Missouri.....	34	1,331.3	3,139.2
Montana.....	9	414.2	997.9
Nebraska.....	28	1,144.8	2,732.6
Nevada.....	2	76.8	234.0
New Hampshire.....	2	86.6	141.8
New Jersey.....	14	567.2	1,041.1
New Mexico.....	11	388.2	1,180.8
New York.....	47	1,978.8	3,556.4
North Carolina.....	22	791.2	1,738.6
North Dakota.....	15	706.2	1,494.2
Ohio.....	52	2,093.6	4,291.7
Oklahoma.....	17	613.7	1,657.6
Oregon.....	20	891.0	2,448.6
Pennsylvania.....	30	1,221.6	2,317.1
Rhode Island.....	7	283.7	500.8
South Carolina.....	14	478.6	1,142.4
South Dakota.....	10	441.4	976.9
Tennessee.....	9	324.0	755.1
Texas.....	57	1,810.0	5,548.5
Utah.....	14	573.1	1,567.0
Vermont.....	3	132.1	216.3
Virginia.....	24	894.9	1,895.8
Washington.....	21	983.8	2,479.2
West Virginia.....	15	602.2	1,199.0
Wisconsin.....	32	1,388.6	2,864.8
Wyoming.....	4	164.6	420.1
Total.....	1,103	43,360.1	99,615.0
Average.....		39.3	90.3

### BOOK REVIEW

#### A B C OF AGROBIOLOGY

By O. W. Willcox. New York: W. W. Norton & Co., Inc. 323 pages, illus. 1937. \$2.75.

AGROBIOLOGY is defined as "the universal quantitative science of plant growth." It is "not concerned with the ecology, physiology, parasitology, pathology, or climatology of plants." It "steers away from the idiosyncrasies and the infinite superficial divergences that exist among the multitudinous forms of plants" and considers those "characteristics and capabilities that are common to all species and varieties." "A universal science of plant growth is possible because roses, tomatoes, rubber trees, sugar cane, onions, garden beets, tulips, orange trees, tea bushes, and all other vegetable organisms that send their roots into the earth and branches into the air have in common certain fundamentally identical characteristics, and react in an identical manner to the same universal factors on which they all depend for their life and growth. . . .

"Because all plants have fundamentally identical natures and react in an identical manner to the same positive external stimulants, the agrobiologists have been enabled to devise an arithmetic of plant growth by which yields may be figured in terms of a known degree of fertility of the soil; or, *vice versa*, to figure how much fertility will be required to produce a desired yield, even the maximum. So that if the gardener or farmer knows in advance how much life is in his seeds and knows what quantity of the factors of plant growth he has at his disposal, he may proceed in the confidence that the harvest will turn out close to what was expected, whether he is growing onions, roses, wheat, gladioli, or whatnot."

These quotations from Chapter I epitomize the philosophy of this book. Mitscherlich is regarded as the founder of the science. His "law of the minimum" is the fundamental principle underlying this "universal science of plant growth". Its fundamental yardstick is the "Baule unit" which is defined as the amount of the limiting factor necessary to produce one-half of the maximum yield. The second Baule unit increases the yield to 75% of the maximum, etc. The tenth unit gives 99.99% of the maximum and for practical purposes this is considered as the "perultimate yield." One Baule unit of nitrogen is regarded as 225 pounds per acre, of phosphoric acid 45, and of potash 82 pounds per acre. The "perfertile" soil should contain 10 Baule units of all the essential elements. Water needs are handled in the same way. The author is apparently unfamiliar with the extensive investigations of Veihmeyer and his co-workers at California.

The absolute size of the maximum yield of any crop is determined by certain internal factors referred to as the "quantity of life." The agrobiologists have a yardstick for this also. This is derived by an analysis of the proportion of the nitrogen present which is actually utilized by plants. The maximum amount which can be absorbed from a perfertile soil is considered to be 318 pounds per acre. A variety of crop plant that can utilize 318 pounds of nitrogen per acre "is the *ne plus ultra* of the plant breeder." By dividing this "constant of

nature" by the actual percentage of nitrogen in any crop we can obtain the maximum possible yield for the species beyond which the plant breeder cannot hope to go! The calculated theoretical yield for corn is 225 bushels (this has been attained), wheat, 171.2 bushels; potatoes, 1,550 bushels (somewhat less than the yield reported from California for water cultures!), sugar cane, 192 tons; and cotton, 4.6 bales.

One chapter is devoted to "Public Soil Science in the United States." A few hot shots are taken at the Soil Survey and of agronomists who refuse to become enthusiastic over the use of chemical analysis as a means of determining fertilizer needs. The author recommends "that if 'leading' agricultural colleges and experiment stations discover among their ranking officials men who can see no correlation between chemical soil analysis and crop response to fertilizer, such officials should forthwith be given sabbatical leave as observers at the Virginia Truck Experiment Station, or some other institution of the same grade."

In addition to being the A B C of Agrobiology one gets the impression that this book is also the X Y Z of the subject. Its problems are solved! The job is done. Its laws are all discovered. They are immutable and universal; any deviations therefrom are to be attributed to certain "sources of frustration" with which the agrobiologist is not concerned. These "sources of frustrations" are left in the lap of the agronomist and other less ethereal groups of scientists. (R. B.)

### AGRONOMIC AFFAIRS

#### THE SOIL CONSERVATION SERVICE GRASS NURSERY AT ITHACA, NEW YORK

**A**GRONOMISTS and others interested in grasses and legumes, when visiting Ithaca, N. Y., will want to spend some time at the Soil Conservation Service, Region 1, Grass Nursery located at Stewart Park.

The Grass Nursery occupies 19 acres of land planted to observational material and 46 acres which are used for increase plots. Here are more than 600 varieties and species of grasses and legumes brought together for study and comparison in order to determine which are best for the various phases of erosion control.

The work is under the direction of Raymond E. Culbertson who extends an open invitation to visitors.

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**T**HE National Fertilizer Association has issued a mimeographed survey of pasture experiments now in progress in the humid sections of the United States prepared by H. R. Smalley and A. L. Grizzard. Copies will be supplied as long as the supply lasts.

In all, 133 projects are listed in 35 states, including more than 300 distinct experiments. In addition to the title and objectives of the project, information is supplied wherever available on the leader, date of initiation, location, source of support, size of plots, fertility treatment, seeding mixtures, methods used in measuring response, chemical analyses, and publications.

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## NEWS ITEMS

IT HAS been announced that Professor Juan Diaz y Munoz, the well-known Spanish soil investigator and director of general agriculture in Spain, fell as a victim of the Spanish Civil War. American soil workers who attended the last International Soil Science Congress in Oxford will well remember the tall figure of the always smiling Spanish scientist. He was a student of Professor Wiegner and contributed considerably to our knowledge of the soils of Spain.

DOCTOR M. F. MILLER, Chairman of the Department of Soils, College of Agriculture, University of Missouri, since 1914, will become Dean and Director of the Missouri Agricultural College and Experiment Station on September 1 next.

THE MEETING of the Corn Belt Section of the Society will be held June 22 and 23 at the Missouri Agricultural Experiment Station and will be preceded by a celebration on June 21 of the 50th anniversary of the establishment of the Experiment Station.

# JOURNAL

OF THE

## American Society of Agronomy

VOL. 30

APRIL, 1938

No. 4

### EFFECT OF SPACING ON THE DEVELOPMENT OF THE FLAX PLANT<sup>1</sup>

A. C. DILLMAN and J. C. BRINSMADE, JR.<sup>2</sup>

IT is a matter of common observation that the growth habits of plants are modified by the space available for their development. Numerous experiments have been conducted to determine the effect of spacing on the plant development and yield of cotton, corn, tobacco, beets, potatoes, and other row crops, and of the small grains. The spacing of flax grown for fiber also has been studied extensively because of the close relation between the stand of plants and the yield, length, and quality of fiber. Few such investigations have been conducted with varieties of flax grown for seed production.

In 1920, Clark<sup>3</sup> reported on the yield and agronomic data of 49 varieties and strains of flax grown at Mandan, N. D., in 1914 to 1916, and Klages,<sup>4</sup> in 1932, reported the results of spacing experiments conducted at Brookings, S. D., in 1930 and 1931.

The experiments herein reported were planned to determine the effect of spacing on the branching habit, height, time of maturity, and yield of seed per plant and per unit area of typical varieties of seed flax.

#### THE FLAX PLANT

The flax plant has three distinct types of branches, namely, (1) basal branches which arise in pairs (i. e., as opposite branches) from the crown of the plant; (2) panicle branches which bear the seed bolls; and (3) adventitious branches which occasionally occur on the main stem. In close spacing the basal branches may be partly or entirely suppressed, whereas, in wide spacing several basal branches may occur. The panicle is formed by the dichotomous branching of the upper part of the stem, each small branch usually terminating in a seed boll. Adventitious branches seldom occur in close stands. They occur most

<sup>1</sup>Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Received for publication December 17, 1937.

<sup>2</sup>Associate Agronomist and Assistant Agronomist, respectively.

<sup>3</sup>CLARK, C. H. Experiments with flax on breaking. U. S. D. A. Bul. 883. 1920.

<sup>4</sup>KLAGES, K. H. Spacing in relation to the development of the flax plant. Jour. Amer. Soc. Agron., 24:1-17. 1932.

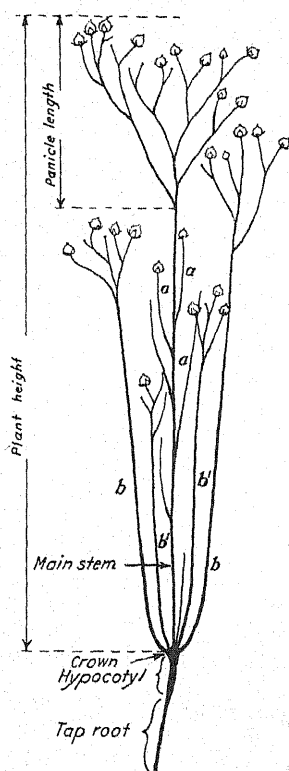


FIG. 1.—Diagram of flax plant showing first pair of basal branches (b-b), second pair of basal branches (b'-b'), and adventitious branches (a). The diameter of main stem is measured at a point 4 or 5 inches above the crown.

commonly on widely spaced plants, or in case the plants are broken down, or when late rains stimulate a secondary vegetative growth (Fig. 1).

#### LOCATION OF THE EXPERIMENTS

The experiments reported in this paper were conducted at the Northern Great Plains Field Station, Mandan, N. D., in 1916, and during the four years, 1926 to 1929, inclusive. The average annual precipitation at Mandan is approximately 16 inches of which about 12 inches occur during the crop growing season of April to August, inclusive. Drought frequently occurs, however, and it is perhaps the chief limiting factor to otherwise successful crop production in that locality.

#### EXPERIMENTAL METHODS

The first spacing experiments herein reported were conducted in 1916, using a single variety, Reserve, C. I. 19. During the four years, 1926 to 1929, two varieties were grown, Linota, a selection of the small-seeded short-fiber type, and Rio, a selection of the large-seeded Argentine type. The plants

were grown in six definite spacings; in close-drilled plats, the rows 6 inches apart and the plants about  $\frac{1}{2}$  inch apart in the row; and in rows 12 inches apart with the plants spaced 1, 2, 3, 4, and 6 inches apart in the row. The seed was sown somewhat thicker than required for the desired stand and the plants thinned to the proper spacing when 1 to 2 inches high. The plats were cultivated and kept entirely free from weeds.

When ripe the plants were pulled, wrapped separately, and hung up to dry, after which the measurements were taken and the seed threshed. In 1929, the more satisfactory procedure of recording the measurements of 50 or more plants as they were pulled and then threshing the plants in bulk after drying, was followed.

The notes included height of plant, length of panicle, number of basal branches, number of bolls on the main stem and on the basal branches, weight of seed, and weight of 1,000 seeds.

## RESULTS OBTAINED IN 1916

The variety Reserve (C. I. 19), a strain of the so-called common or Russian seed flax, was grown in the spacing experiments in 1916. Six plats of four rows 1 foot apart were sown, leaving the plants 1, 2, 3, 4, 5, and 6 inches apart, respectively, in the rows. The two inner rows in each plat were harvested, leaving a border row on each side of the plat in which the plants were spaced the same as in the harvested rows.

The crop of 1916 was grown on virgin soil. The native sod was plowed in 1914 and kept fallow in 1915, a season of abundant rainfall. At the time of seeding the soil was moist to a depth of 6 feet or more, and although the seasonal rainfall was below normal, the crop did not appear to be checked appreciably from lack of moisture. The seasonal precipitation, April to August, was 10.5 inches (Table 3).

Some loss of plants from "heat canker" occurred after the rows were thinned, so that the spacing at time of harvest was not entirely uniform. The average spacing at time of harvest ranged from 1.1 inches in plat 1, the closest spacing, to 7.3 inches in plat 6, the widest spacing. The plants probably were somewhat more variable than they would have been if a uniform stand had been maintained. Where a plant is missing from any cause the adjacent plants are likely to be larger because of the extra space available for their development. In the experiments of 1916, all the plants in each plat were pulled. In the later experiments only plants which were spaced correctly were harvested, that is, plants adjacent to a space marking a missing plant were not harvested.

A summary of the average values of the several plant characters measured in 1916 is presented in Table 1. The number of plants measured was sufficient for an adequate sample of each spacing, the number ranging from 234 plants in the 4-inch spacing to 513 plants in the 1-inch spacing.

The average height of plants ranged from 50 cm in the 1-inch spacing to 55 cm in the 3-inch spacing, an extreme range of only 5 cm.

The length of panicle of the main stem, as measured from the base of the lowest panicle branch to the tip of the panicle, ranged from 15.7 cm in the 1-inch spacing to 25.6 cm in the 5-inch spacing.

The number of basal branches appears to be dependent on the space available to the plant for development. In the experiments of 1916, the average number of basal branches ranged from 0.2 per plant in plat 1 to 2.7 in plat 6. As mentioned previously, the basal branches occur in pairs so that there is a tendency for the plants in wider spacing to have two, or frequently four, basal branches. In many plants, however, one branch of the pair is suppressed. Typical plants in 1-inch spacing had no basal branches, all being suppressed. In Table 2 the percentage of plants having from 0 to 6 basal branches is recorded.

The number of bolls on the panicle of the main stem and on the basal branches were recorded separately. Since there were very few basal branches in the 1-inch spacing, the bolls occurred chiefly on the panicle of the main stem. The total number of bolls increased more or less regularly from the 1-inch to the 6-inch spacing, the number ranging

TABLE 1.—Average plant measurements of Reserve flax spaced from 1 to 6 inches apart in rows 1 foot apart at Mandan, N. D., in 1916.

Plant measurements	Plat No. 1	Plat No. 2	Plat No. 3	Plat No. 4	Plat No. 5	Plat No. 6
Spacing, inches:						
Theoretical, as first spaced.	1	2	3	4	5	6
Actual, at time of harvest.	1.1	2.3	3.3	4.9	5.7	7.3
Number of plants measured.	513	252	264	234	252	238
Height, cm.	50.0	53.3	55.1	54.0	54.3	54.3
Length of panicle, cm.	15.7	20.5	24.3	24.6	25.6	24.9
Number of basal branches.	0.2	0.8	1.8	2.2	2.2	2.7
Number of bolls:						
On main stem.	12	22	27	34	32	32
On basal branches.	1	4	12	19	18	24
Total per plant.	13	26	39	53	50	56
Yield:						
Seeds per boll.	6.5	6.3	5.9	5.5	6.1	6.3
Seed per plant, grams.	0.39	0.75	1.05	1.34	1.38	1.60
Bushels per acre.	7.1	6.8	6.6	5.6	5.0	4.6
Weight of 1,000 seeds, grams.	4.61	4.61	4.57	4.56	4.50	4.52
Oil content on dry basis, %.	39.0	39.2	38.9	38.3	38.8	38.8
Iodine value, Wijs method.	177	177	177	175	174	176

TABLE 2.—The effect of spacing on the number of basal branches in Reserve flax plants grown at Mandan, N. D., 1916.

Spacing, inches	Number of plants	Number of basal branches and percentage of plants in each group						
		0	1	2	3	4	5	6
1	513	90	5	4	1	0	0	0
2	252	56	17	23	2	2	0	0
3	264	18	17	46	12	7	0	0
4	234	6	13	39	26	16	0	0
5	252	5	18	39	18	18	2	0
6	238	1	6	36	27	27	2	1

from 13 per plant in the 1-inch spacing to 56 per plant in the 6-inch spacing.

The yield of seed per plant is, of course, directly correlated with the number of bolls. The yield of seed increased from 0.39 gram per plant in the 1-inch spacing to 1.6 grams in the 6-inch spacing. The increase in the wider spacing, however, was not in proportion to the space available and, therefore, the yield per unit area decreased as the spacing increased. The computed yield ranged from 7.1 bushels per acre in the 1-inch spacing to 4.6 bushels in the 6-inch spacing (Table 1).

The comparative size of the seeds of flax is conveniently expressed by the weight of 1,000 seeds. In this experiment there was no significant difference in weight of 1,000 seeds, nor in the oil content, nor in the iodine number of the oil, as determined by analyses of seed samples from the several spacings. The weight of 1,000 seeds averaged approxi-

mately 4.55 grams, the oil content 38.8% on dry basis, and the iodine number 176 (Table 1).

### RESULTS OBTAINED 1926 TO 1929

As previously mentioned, two varieties, Linota and Rio, were grown in the spacing experiments from 1926 to 1929, inclusive. Seasonal rainfall and somewhat different soil conditions are sufficient to account for the variation in plant characters observed during the four seasons. In 1926 and 1927 the experimental plats were on soil that had grown flax the previous season; in 1928, the crop was grown on brome grass sod plowed the previous summer; and in 1929, on adjacent sod land kept fallow in 1928. The seasons of 1926 and 1929 were relatively dry, while 1927 and 1928 were above normal in total rainfall. However, the months of June and July, 1927, were dry, and the early season of 1928 (May to June 12) was extremely dry. The rainfall in inches during the crop growing season, the evaporation from a free-water surface, and the ratio of precipitation to evaporation each season are shown in Table 3.

TABLE 3.—Seasonal precipitation, evaporation from a free water surface, and ratio of precipitation to evaporation in 1916 and in 1926 to 1929 at Mandan, N. D.

	Precipitation, inches				
	1916	1926	1927	1928	1929
Apr. ....	0.93	0.13	1.37	0.99	1.75
May. ....	1.69	2.41	6.65	0.55	2.68
June. ....	2.25	1.20	2.00	6.32	0.99
July. ....	3.55	2.19	2.37	4.94	1.20
Aug. ....	2.04	1.31	3.16	2.24	0.81
Total. ....	10.46	7.24	15.55	15.04	7.43
Evaporation, Apr. to Aug. ....	26.88	30.77	24.25	27.77	29.82
Ratio, Prec/Evap. ....	0.39	0.24	0.64	0.54	0.25

The number of plants measured in each spacing was 50 or 100 in most cases. In the wider spacings, however, there was some loss of plants from heat canker, especially in 1926, and in such cases somewhat less than 50 plants were available for measurement. In a few plats in close stands over 200 plants were measured. A summary of the several characters measured is given in Tables 4 and 5.

In these tables, the plats referred to as "close stand" were sown in drill rows 6 inches apart and there were approximately 24 plants per foot of row, or 48 plants per square foot. In all other plats the rows were 12 inches apart and the plants spaced approximately 1, 2, 3, 4, and 6 inches apart in the row, that is, there were 12, 6, 4, 3, and 2 plants, respectively, per square foot of space.



TABLE 4.—Average plant measurements of *Linota* and *Rio flax* grown in six spacings at Mandan, N. D., 1926 to 1929.

Variety and spacing	Measurements recorded				
	1926	1927	1928	1929	Average

A. Number of Plants Measured

Linota:					
Close stand.....	200	100	50	50	
1 inch.....	280	100	50	50	
2 inches.....	100	100	50	50	
3 inches.....	80	73	50	50	
4 inches.....	60	54	50	50	
6 inches.....	40	30	50	50	
Rio:					
Close stand.....	200	100	50	50	
1 inch.....	100	100	50	50	
2 inches.....	70	100	50	50	
3 inches.....	40	100	50	50	
4 inches.....	30	80	42	50	
6 inches.....	15	55	45	50	

B. Height of Plants, cm

Linota:					
Close stand.....	23.2	43.6 *	61.4±.51	43.8±.39	43.0
1 inch.....	41.2	57.4	71.0±.61	57.8±.35	56.9
2 inches.....	48.3	63.3	73.0±.76	59.6±.23	61.1
3 inches.....	51.5	64.3	75.1±.55	62.1±.34	63.3
4 inches.....	57.0	65.4	74.7±.70	60.6±.39	64.4
6 inches.....	57.0	63.1	69.0±.87	59.8±.39	62.2
Rio:					
Close stand.....	23.2	36.8	55.7±.48	39.3±.42	38.8
1 inch.....	43.6	41.0	65.7±.46	46.3±.37	49.2
2 inches.....	49.1	45.0	63.2±.50	51.9±.39	52.3
3 inches.....	50.8	45.6	64.0±.63	55.3±.41	53.9
4 inches.....	55.4	46.7	60.0±.58	54.9±.35	54.3
6 inches.....	54.0	45.5	58.4±.51	54.7±.44	53.2

C. Diameter of Main Stem, mm

Linota:					
Close stand.....	0.83	1.12	1.36±.03	1.34±.02	1.16
1 inch.....	1.61	1.88	2.15±.03	2.20±.02	1.96
2 inches.....	2.10	2.28	2.54±.02	2.33±.01	2.31
3 inches.....	2.30	2.59	2.93±.02	2.51±.02	2.58
4 inches.....	2.51	3.00	3.04±.04	2.65±.02	2.80
6 inches.....	2.94	3.08	3.48±.04	2.87±.03	3.09
Rio:					
Close stand.....	0.98	1.44	1.22±.03	1.39±.01	1.26
1 inch.....	1.92	1.67	2.08±.02	1.64±.02	1.83
2 inches.....	2.06	1.86	2.32±.02	1.91±.02	2.04
3 inches.....	2.45	2.03	2.48±.02	2.10±.02	2.27
4 inches.....	2.93	2.34	2.64±.03	2.16±.02	2.52
6 inches.....	2.82	2.29	2.77±.04	2.42±.03	2.58

TABLE 4.—Continued.

Variety and spacing	Measurements recorded				
	1926	1927	1928	1929	Average
D. Number of Basal Branches					
Linota:					
Close stand . . . . .	0.0	0.0	0.0	0.0	0.0
1 inch . . . . .	0.6	0.5	1.8	1.9	1.2
2 inches . . . . .	2.2	2.0	2.3	3.0	2.4
3 inches . . . . .	3.4	2.7	4.1	3.9	3.5
4 inches . . . . .	3.9	3.2	4.1	4.1	3.8
6 inches . . . . .	5.0	4.2	4.3	5.5	4.8
Rio:					
Close stand . . . . .	0.1	0.2	0.0	0.2	0.1
1 inch . . . . .	3.2	1.7	2.3	3.3	2.6
2 inches . . . . .	3.8	3.2	3.9	4.3	3.8
3 inches . . . . .	5.8	3.5	4.1	6.2	4.9
4 inches . . . . .	6.1	3.7	5.2	7.1	5.5
6 inches . . . . .	7.5	4.2	6.7	8.0	6.6
E. Number of Bolls					
Linota:					
Close stand:					
Main stems . . .	2.0	3.5	5.4	5.1	4.0
1 inch:					
Main stems . . .	10.1	15.3	13.3	18.0	14.2
Basal branches .	1.2	10.3	4.7	5.8	5.5
Total per plant.	11.3	25.6	18.0	23.8	19.7
2 inches:					
Main stems . . .	17.6	25.8	21.5	19.7	21.2
Basal branches .	10.2	10.4	12.4	12.1	11.3
Total per plant.	27.8	36.2	33.9	31.8	32.5
3 inches:					
Main stems . . .	23.0	32.6	28.8	25.2	27.4
Basal branches .	21.4	20.3	29.7	24.6	24.0
Total per plant	44.4	52.9	58.5	49.8	51.4
4 inches:					
Main stems . . .	26.7	39.8	35.4	29.8	32.9
Basal branches .	26.0	29.7	32.8	38.1	31.7
Total per plant.	52.7	69.5	68.2	67.9	64.6
6 inches:					
Main stems . . .	36.9	39.3	43.8	35.5	38.9
Basal branches .	39.2	45.6	51.0	49.1	46.2
Total per plant.	76.1	84.9	94.8	84.6	85.1
Rio:					
Close stand:					
Main stems . . .	1.0	6.5	3.5	1.1	3.0
1 inch:					
Main stems . . .	8.2	10.9	14.8	2.7	9.2
Basal branches .	12.2	4.8	14.1	7.5	9.7

TABLE 4.—Continued.

Variety and spacing	Measurements recorded				
	1926	1927	1928	1929	Average
E. Number of Bolls—Continued					
Rio:					
Total per plant.	20.4	15.7	28.9	10.2	18.9
2 inches:					
Main stems. . . .	10.7	16.9	19.2	4.1	12.7
Basal branches.	18.3	15.8	29.1	18.1	20.3
3 inches:					
Total per plant.	29.0	32.7	48.3	22.2	33.0
Main stems. . . .	18.8	23.6	21.6	7.0	17.8
Basal branches.	39.5	22.3	41.1	30.5	33.4
4 inches:					
Total per plant.	58.3	45.9	62.7	37.5	51.2
Main stems. . . .	25.6	31.6	29.5	7.3	23.5
Basal branches.	55.6	27.3	53.4	38.1	43.6
6 inches:					
Total per plant.	81.2	58.9	82.9	45.4	67.1
Main stems. . . .	24.2	32.0	30.1	12.6	24.7
Basal branches.	65.5	32.8	65.0	48.7	53.0
Total per plant.	89.7	64.8	95.1	61.3	77.7
F. Seed per Plant, grams					
Linota:					
Close stand. . . . .	0.04	0.11	0.10	0.12	0.09
1 inch. . . . .	0.23	0.36	0.34	0.41	0.34
2 inches. . . . .	0.76	0.73	0.92	0.63	0.76
3 inches. . . . .	0.99	1.23	1.30	1.14	1.17
4 inches. . . . .	1.27	1.78	1.66	1.47	1.55
6 inches. . . . .	1.84	2.11	2.21	1.62	1.95
Rio:					
Close stand. . . . .	0.02	0.18	0.14	0.03	0.09
1 inch. . . . .	0.38	0.53	0.88	0.16	0.49
2 inches. . . . .	0.67	1.31	1.41	0.56	0.99
3 inches. . . . .	1.70	1.66	1.96	0.96	1.57
4 inches. . . . .	1.80	2.22	2.86	1.24	2.03
6 inches. . . . .	2.24	2.53	3.62	1.92	2.58
G. Weight of 1,000 Seeds, grams					
Linota:					
Close stand. . . . .	3.07	3.98	3.70	2.76	3.38
1 inch. . . . .	3.21	4.07	3.73	2.77	3.45
2 inches. . . . .	3.23	4.18	3.79	2.83	3.51
3 inches. . . . .	3.38	4.07	3.75	3.07	3.57
4 inches. . . . .	3.40	4.03	3.73	3.12	3.57
6 inches. . . . .	3.48	4.10	3.85	3.11	3.64
Annual average	3.30	4.07	3.76	2.94	3.52

TABLE 4—*Concluded.*

Variety and spacing	Measurements recorded				
	1926	1927	1928	1929	Average
Weight of 1,000 Seeds, grams— <i>Continued</i>					
Rio:					
Close stand. . . . .	5.60	6.86	6.53	5.52	6.13
1 inch. . . . .	5.78	6.84	6.53	5.75	6.23
2 inches. . . . .	5.90	7.29	6.38	5.92	6.37
3 inches. . . . .	6.00	7.48	6.53	5.84	6.46
4 inches. . . . .	5.78	7.27	6.27	5.96	6.32
6 inches. . . . .	5.78	7.61	6.64	5.90	6.48
Annual average	5.81	7.23	6.48	5.82	6.33
H. Computed Yield in Bushels per Acre*					
Linota:					
Close stand. . . . .	3.3	9.1	8.2	8.1	7.2
1 inch. . . . .	4.7	7.4	7.0	7.6	6.7
2 inches. . . . .	7.8	7.5	9.5	7.1	8.0
3 inches. . . . .	6.8	8.5	9.0	7.5	8.0
4 inches. . . . .	6.5	9.1	8.5	7.1	7.8
6 inches. . . . .	6.3	7.2	7.5	6.1	6.8
Rio:					
Close stand. . . . .	1.6	14.8	11.5	3.2	7.8
1 inch. . . . .	7.8	10.9	18.1	4.4	10.3
2 inches. . . . .	6.9	13.5	14.5	5.0	10.0
3 inches. . . . .	11.7	11.5	13.5	5.8	10.6
4 inches. . . . .	9.2	11.3	14.6	5.6	10.2
6 inches. . . . .	7.6	8.6	12.3	6.3	8.7

\*Yield in 1926, 1927, and 1928 is computed on the basis of seed per plant (Table 4 F) and full stand of plants, that is, 824 plants per plat in close stand, 206 plants per plat spaced 1 inch apart, 103 plants spaced 2 inches, 69 plants spaced 3 inches, 51 plants spaced 4 inches, and 34 plants spaced 6 inches. In 1929, all plants were harvested and the acre yield is based on the actual yield per plat.

## DISCUSSION

In reviewing the results of the experiments from 1926 to 1929 (Tables 4 and 5), it is of interest to note (1) the effects of spacing, (2) the effect of season, principally rainfall, and (3) the behavior of the two varieties. The seasons of 1927 and 1928 were fairly favorable, whereas 1926 and 1929 were relatively dry.

In height, the plants in close stand were of shorter growth in every case. In the 12-inch rows there was some increase in height from the 1-inch to the 4-inch spacing. In most cases the plants in the 6-inch spacing were shorter than in the 4-inch spacing. The effect of season (rainfall) on height of plants was marked as may be seen by comparing 1926 and 1928 or 1928 and 1929. Seasonal effects were perhaps greater than varietal differences.

In diameter of the main stem there was a marked and constant increase in size of stems as the spacing increased. Moreover, the diameter of the stems was very uniform in each spacing as shown by the small probable error in the measurements of 1928 and 1929. The stems of Linota were larger than those of Rio, except in close stands. No doubt

TABLE 5.—Oil content and iodine number (Wijs method) of *Linota* and *Rio* flax plants grown in six spacings at Mandan, N. D., 1928 to 1929.

Spacing	Oil content (dry basis), %			Iodine No.		
	1928	1929	Average	1928	1929	Average
<i>Linota</i>						
Close spacing . . . . .	36.4	33.2	34.8	182	169	176
1 inch . . . . .	36.5	33.1	34.8	182	171	177
2 inches . . . . .	36.4	33.5	35.0	186	174	180
3 inches . . . . .	36.9	34.1	35.5	186	179	183
4 inches . . . . .	37.3	34.5	35.9	187	179	183
6 inches . . . . .	37.8	34.1	36.0	188	180	184
Annual average . . . .	36.9	33.8	—	185	175	—
<i>Rio</i>						
Close spacing . . . . .	39.6	37.5	38.6	180	171	176
1 inch . . . . .	40.9	38.6	39.8	180	174	177
2 inches . . . . .	40.3	38.7	39.5	179	177	178
3 inches . . . . .	41.2	38.9	40.1	183	175	179
4 inches . . . . .	41.7	38.9	40.3	185	176	181
6 inches . . . . .	41.5	40.0	40.8	186	177	182
Annual average . . . .	40.9	38.8	—	182	175	—

this difference is associated with the number of basal branches. The development of a greater number of basal branches on *Rio* than on *Linota* had the effect of reducing the growth of the main stem, somewhat as the closer spacing did.

The number of basal branches is determined chiefly by the space available and to a less extent probably by seasonal conditions and by variety. The average number of basal branches in *Linota* ranged from 0 in close stand to 4.8 per plant in the 6-inch spacing, and in *Rio* from 0.2 in close stand to 6.6 per plant in the 6-inch spacing (Fig. 2).

The number of bolls per plant (Table 4, E) was not significantly different in the two varieties. The average in *Linota* ranged from 4.0 per plant in close stand to 85.1 in the 6-inch spacing and in *Rio* from 3.0 in close stand to 77.7 per plant in the 6-inch spacing.

In average yield of seed per plant (Table 4, F), *Linota* ranged from 0.9 grams in close stand to 1.94 grams in the 6-inch spacing and *Rio* from 0.09 to 2.58 grams. The yield of seed is, of course, closely correlated with the number of bolls per plant, that is, within each variety. The yield, however, is determined in part by the size of seeds, and by the number of seeds per boll. The average weight of 1,000 seeds of *Linota* was 3.52 grams as compared with 6.33 grams for *Rio*, a ratio of 1:1.8. On the average, the yield of seed from 100 bolls of *Linota* was 2.27 grams and from *Rio* 3.09 grams, a ratio of 1:1.36. On the average, therefore, *Linota* had 6.4 seeds per boll and *Rio* 4.9 seeds per boll. The flax boll when filled has 10 seeds, rarely or never any more, except in abnormal twin bolls.

The computed yield of seed in bushels per acre, based on a full stand, is given for 1926, 1927, and 1928, whereas the actual yield in 1929 is

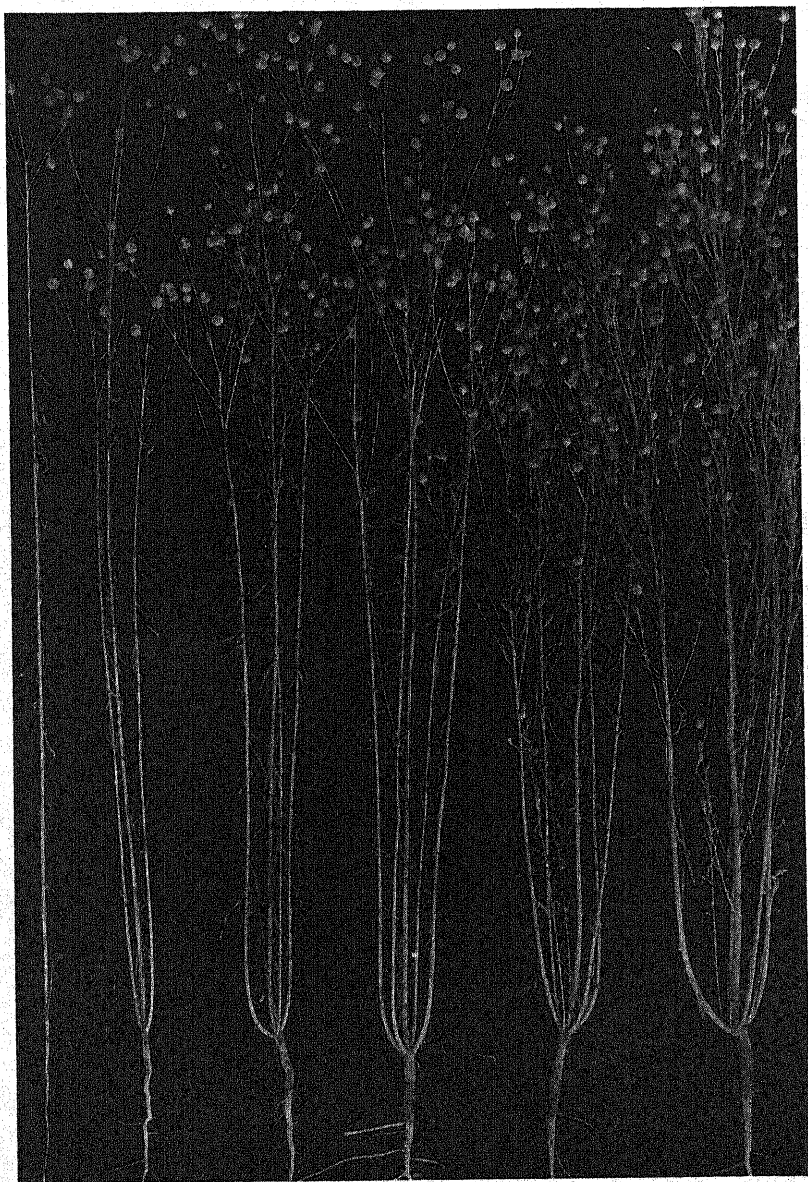


FIG. 2.—Typical plants of Rio flax grown at Mandan, N. D., in 1928. The plant at left in close stand, the others (left to right) spaced 1, 2, 3, 4, and 6 inches apart, respectively, in rows 1 foot apart. Linota plants showed similar characteristics of branching. (Photograph by J. C. Thysell.)

given. It is recognized that the computed yields are subject to error, because of the limited number of plants observed. The yields, however, are within the range of actual yields obtained in other varietal experiments during the same years. This was primarily a study of plant development, not a yield test.

The oil content of the seed and the iodine number of the expressed oils of each variety increased more or less uniformly from the close spacing to the 4- and 6-inch spacings. As found in numerous other experiments, the oil content is correlated with the weight of 1,000 seeds. Both the size of seeds and the oil content are determined in part by the quantity of soil moisture available to the plant. This is seen in comparing the data of 1928, when the seasonal rainfall was favorable, with 1929, a dry season.

The data show that every vegetative character of the plant is influenced by the space available for plant development. In making plant selections, therefore, the flax breeder should consider the importance of spacing in relation to the height, diameter of stem, number of basal branches, number of bolls, and yield of seed. With plants spaced either 2 or 3 inches apart, in rows 1 foot apart, the vegetative characters of individual plants can be observed and compared, and the yield of seed per plant is adequate for planting in short rows for further increase.

The data indicate also that the use of vegetative characters in the classification of flax varieties must be used with caution unless the varieties are grown under identical methods of spacing and identical soil and moisture conditions.

## NATURAL CROSSING IN FLAX<sup>1</sup>

A. C. DILLMAN<sup>2</sup>

IN a study of the classification of flax varieties, the writer has observed considerable variations in the uniformity, from year to year, of single line selections of distinct flower types. In many cases the mixtures that occurred obviously were the result of natural crossing. This suggested a study of the extent of natural crossing among varieties of flax of distinct flower types, in which hybrids could be recognized readily. The results of this study, together with some observations on the time of pollination and fertilization in flax, are reported here.

The literature on natural crossing in flax has been reviewed by Henry and Tu (2)<sup>3</sup> and by Robinson (5) and will not be repeated here. The extent of natural crossing reported has ranged from 0 to 5% or more.

### THE FLAX FLOWER

Four quite distinct forms of flowers (Fig. 1) occur in varieties of cultivated flax, *viz.*, (a) the common funnellform flower, as in Redwing, Bison, and Punjab; (b) the disk-shaped flower with large, flat petals as in Malabrigo, Rio, and Cyprus; (c) the star-shaped flower with narrow in-rolled or involute petals as in Tammes' "Crimped White"; and (d) the tubular flower found in two strains of Indian flax, C. I.

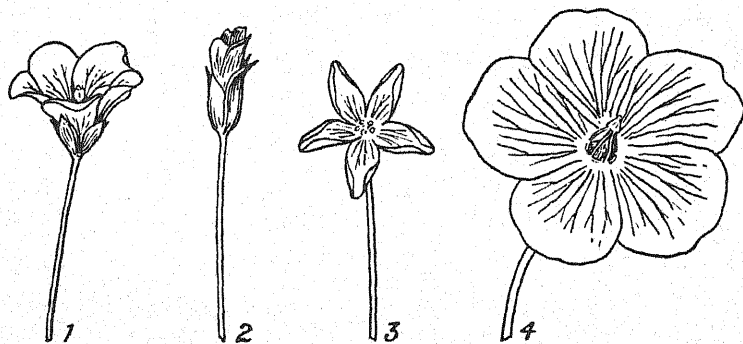


FIG. 1.—Flax flowers of the four principal types. (1) The common or funnellform; (2) tubular; (3) star-shaped or "crimped-white"; and (4) the large disk-shaped.

<sup>1</sup>Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Received for publication January 10, 1938.

<sup>2</sup>Associate Agronomist. The experiments at St. Paul, Minn., and Bozeman, Mont., were conducted in cooperation with the state agricultural experiment stations. The author is indebted to A. C. Arny and to J. C. Brinsmade, Jr., for assistance in taking notes at St. Paul and at Mandan, respectively, and for reading the manuscript.

<sup>3</sup>Figures in parenthesis refer to "Literature Cited," p. 286.



156,<sup>4</sup> and Type 68 of Howard and Kahn (3). Somewhat intermediate forms also are found among the numerous varieties of cultivated flax.

The tubular flower is very unusual. The petals ordinarily remain rolled in the form of a tube open slightly at the tip. This is caused, according to observations of the writer, by the firm thick sepals which prevent the petals from spreading. If one or two sepals are spread slightly with a needle point, the petals open at once like a funnelliform flower. However, in the humid atmosphere of the greenhouse the turgid petals exert sufficient pressure to separate the sepals and permit the flower to open. In a dry atmosphere the flowers remain tubular and the petals wither without dropping off. In this condition the dry petals form a closed sack, covering the stigma which lessens the chance of cross pollination and also protects the style and anthers from the drying effect of hot winds. Because of its shape, there is little natural crossing in the tubular flowers.

In the typical flax flower of most varieties the anthers entirely surround and over-top the stigma. In some varieties, however, the tip of the stigma is likely to be exerted slightly above the anthers, and thus is exposed to possible cross-pollination. This condition occurs most often in the large, disk-shaped flowers, especially in dry, hot

weather, which probably accounts for the greater frequency of natural crossing often observed in varieties of this type. Many wild species of *Linum* are heterostyled and possibly a factor for this condition (length of filaments) exists in cultivated flax.

In crosses of Indian Type 46 (3) by two strains of dehiscent flax (var. *crepitans*), C. I. 759 from Ukraine and C. I. 760 from Germany (1), the  $F_1$  generation had flowers with short stamens (filaments) and was almost self-sterile when grown in the greenhouse (Fig. 2). The flowers, however, were quite normal when grown in the field at Bozeman in 1937.

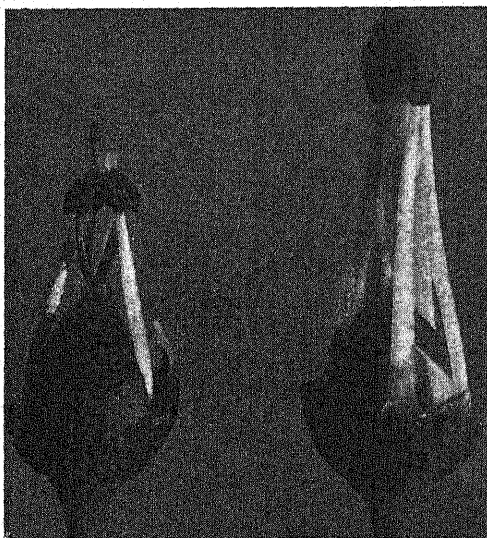


FIG. 2.—Flax flowers with sepals cut away and petals removed to show the inner parts. The flower at left, an  $F_1$  hybrid of *crepitans* (dehiscent)  $\times$  Indian Type 46, had short filaments and was nearly self sterile when grown in the greenhouse. At right, a flower of normal type with anthers completely surrounding and overtopping the stigma, thus assuring self pollination.  $\times 8$ .

In rare cases the anthers are partly or wholly deficient in pollen. Such flowers usually remain open all day and thus are more exposed to outcrossing than the normal flower. In a cross of Bison  $\times$  (Argentine, C. I. 160  $\times$  Winona), 3.3% of plants with deficient anthers were found in the progeny of an  $F_2$  plant selection. A panicle of such a plant (1 of 20 found in a plat of 600 plants) is shown in Fig. 3.

#### TIME OF POLLINATION

The flower bud of flax opens at sunrise on clear, warm days and pollination occurs at once. On cool, cloudy days, however, the flowers open much later, or, in rare cases, the buds open only partly the first day and reopen fully the following day (3). The writer has made numerous observations on the time of opening of flax flowers. At St. Paul, Minn., on June 27, 1926, 10 buds each of N.D.R. 114 and Rio (Argentine) were observed. The sun rose at 4:26; the temperature at 5 o'clock was 54°, at 7 o'clock, 60°, at 9 o'clock, 68°, and at noon, 80° F. On all buds of both varieties the petals began to spread at 4:45; the flowers were partly open and the anthers dehiscid at 4:50 to 5:15; the flowers were fully open (funnelform) at 6:40 to 7 o'clock; and the petals dropped off between 10:30 a.m. and noon.

At San Antonio, Texas, 12 buds of N.D.R.

114 were observed on April 25, 1926. The day was cool and partly cloudy; the minimum temperature was 56°, the maximum 73° F; the sun rose at 5:58. The buds began to open at 6:30; the anthers were visible and dehiscing at 6:30 to 7:15; the flowers were fully open (funnelform) at 9 o'clock; and the petals fell between 11:30 and 1:15.

Observations were made on 20 flowers of each of three varieties at Bozeman, Mont., July 22, 1928. The flower buds were tagged with woolen yarn the previous evening. The sun rose at 5:30; the day was clear; the temperature was 50° F at 5 a.m., 57° at 6, 68° at 8, 78° at noon, and 85° at 3 p.m. The observations are recorded in Table 1.



FIG. 3.—A plant (A) with deficient anthers found in a cross of Bison  $\times$  (Argentine  $\times$  Winona). A normal plant (B) is shown at right.

TABLE I.—*Progress of blooming of 20 flowers of each of three varieties of flax at Bozeman, Mont., July 22, 1928.*

Variety	Anthers dehiscent			Flower fully open			Petals fallen		
	Earliest	Latest	Av.	Earliest	Latest	Av.	Earliest	Latest	Av.
Novelty, C. I. 140. . . . .	6:10	6:35	6:18	7:10	7:30	7:21	11:50	4:10	2:10
Argentine, C. I. 472. . . .	6:00	6:30	6:12	7:30	8:00	7:37	11:00	4:00	1:50
Indian Type 41. . . . .	6:20	7:25	6:43	7:40	8:20	7:52	11:50	5:00	2:32

## FERTILIZATION

Fertilization of the ovules takes place within a few hours after pollination as determined by rather crude experiments conducted in the field. In a preliminary experiment conducted at St. Paul, July 28, 1926, the pistils of a number of flowers were cut off with dissecting

scissors at a point just below the stigma. When this was done at 8:10 a.m., some 3 hours after pollination, the bolls developed normally, indicating that fertilization had occurred, or, at least that the pollen tubes had penetrated the style before the stigmas were removed. On the same day, the styles of other flowers were cut off close to the ovary or boll (Fig. 4). This was done at 8:10 a.m. and again at 1:20 p.m. In flowers clipped at 8:10 no further growth of the bolls occurred; whereas, in flowers clipped at 1:20 the bolls developed in a normal manner, indicating that fertilization had occurred before 1:20. The normal development of the seeds indicated, also, that there was no serious injury to the boll (ovary) by this treatment.

The experiments were repeated at the Agricultural Experiment Station, Bozeman, Montana. In these experiments the pistils were cut off close to the boll as shown in Fig. 4. In flowers clipped at 7:30 and at 9:30,

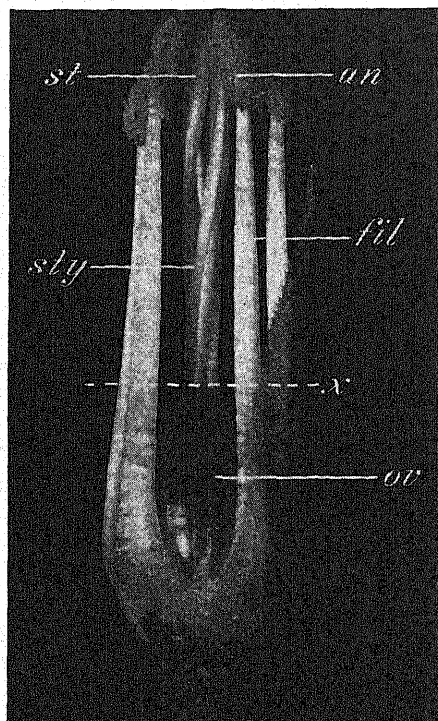


FIG. 4.—Inner parts of flax flower showing the dehiscent anthers (*an*), filaments (*fil*), boll or ovary (*ov*), style (*sty*), and stigma (*st*). To determine approximately the time of fertilization, the style and filaments were cut off at the line X.

Aug. 5, 1926, the bolls did not develop; whereas, those clipped at 11:30 a.m. and at 1:30 p.m. developed normal bolls.

On July 22, 1928, the styles of 10 flowers were clipped close to the boll, as shown in Fig. 4, at 9:15, at 10:30, and 11:45 a.m. All bolls developed and the number of seeds in each was as follows:

Boll No.	Number of seeds developed per boll when pistils were cut off at hour indicated		
	9:15 a. m.	10:30 a. m.	11:45 a. m.
1.....	6	8	10
2.....	2	8	10
3.....	1	9	10
4.....	8	9	7
5.....	8	9	10
6.....	5	8	7
7.....	7	10	9
8.....	9	5	8
9.....	10	10	5
10.....	3	8	9
Average.....	5.9	8.5	8.5

The results indicate that fertilization was incomplete in bolls 2, 3, and 10, clipped at 9:15, as only one to three seeds developed in each boll. Pollination had occurred at about 6:15, some three hours before the styles were cut off. In flowers clipped at 10:30 and at 11:45 a normal number of seeds developed, indicating that fertilization had occurred before 10:30 a.m. The normal development of the seeds indicated, again, that there was no injury to the boll by this treatment.

#### NATURAL CROSSING AMONG VARIETIES

In order to determine the extent of natural crossing in flax seven varieties were chosen that were distinct in shape of flower and in color of petals and other flower parts, so that hybrids could be recognized readily. The varieties were as follows:

1. Blanc (C. I. 323-3).—Flower saucer-shaped; petals large, white; anthers blue, filaments white; style white; bolls semidehiscent; seeds brown, large; plant short, early to midseason.

2. Indian Type 68 of Howard and Kahn (3).—Flower tubular; petals blue; anthers blue, filaments trace of blue; style light blue at base; bolls indehiscent; seeds brown, midsize; plant very short, early to midseason.

3. Pale Malabrigo (C. I. 690).—Flower large, saucer-shaped; petals large, pale blue or "Verbena Violet", Plate 37 of Ridgway (4); anthers blue, filaments white; style white; bolls indehiscent; seeds brown, large; plant stout, short to midheight, midseason.

4. "Crimped White" (C. I. 392).—Flower funnellform; petals white, narrow, separate, inrolled at margins; anthers yellow, filaments white; style white; bolls semidehiscent; seeds greenish-yellow, small; plant midheight, early to midseason.

5. Tall Pink (C. I. 451-3).—Flower funnelform; petals pink; anthers yellow; filaments pale blue; style trace of blue; bolls semidehiscent; seeds "dresden brown" (Plate 15, Ridgway), small; plant tall, midseason to late.

6. Ottawa 770B (C. I. 355).—Flower similar to "Crimped White" but slightly larger; petals white, narrow, separate, inrolled at margins; anthers yellow, filaments white; style white; bolls semidehiscent; seeds yellow, midsize; plant midheight, midseason to late.

7. Bison (C. I. 389).—Flower funnelform; petals deep blue or "Wistaria blue" (Plate 23, Ridgway); anthers blue; filaments about  $\frac{1}{3}$  light blue; style  $\frac{1}{3}$  blue; bolls semidehiscent; seeds brown, midsize; plant midheight, midseason.

In the blue-flowered varieties, Bison, Indian Type 68, and Pale Malabrigo, the petals have veins of a deeper shade than the "intervenía", the space between the veins. In Tall Pink the veins are light violet. In varieties with broad white petals and blue anthers, like Blanc, the veins are colorless, and in crosses with blue-flowered varieties the petals in the  $F_1$  generation are light blue *without veins*, that is, the veins are the same color as the intervenía. Such hybrids are easily recognized. The petals of "Crimped White" and Ottawa 770 B also are white, *without veins*, but in crosses with blue the  $F_1$  has veins.

The natural crossing experiments were conducted at University Farm, St. Paul, Minn., and at the Northern Great Plains Field Station, Mandan, N. D., in the three seasons, 1931 to 1933. Each variety was planted in a single row alternating with a single row of Bison and the plat bordered with two rows of Bison. The rows were 18 feet long and 1 foot apart. The planting was a part of a large flax nursery and, therefore, exposed to possible natural crossing with many varieties and strains.

The seed used in 1931 was obtained from the flax nursery grown at Bozeman, Mont., in 1930. The rows of each variety were rogued and the seed for planting examined carefully to make sure that it was pure. The hybrids found in 1931, therefore, should represent the natural crossing that occurred at Bozeman in 1930. Seed from each row, including Bison, was harvested carefully in 1931 and planted in 1932 and the same process repeated for the planting of 1933. Seed from all supposedly hybrid plants was sown the year after the plants were found to determine if they segregated and thus verify their hybrid condition. The results are reported in Table 2.

## DISCUSSION

As had been observed previously, the greatest percentage of natural crossing occurred in the large-flowered varieties, Blanc and Pale Malabrigo, and very much less in the tubular-flowered variety, Indian Type 68. On the average, about 1.9% of natural crosses was observed in Blanc and only 0.3% in Indian Type 68. A maximum of 5% occurred in Blanc at Mandan in 1932, and 1% in Type 68 at St. Paul in 1932.

It is noteworthy that no natural crossing was observed in more than 8,000 plants of Bison flax grown during the three seasons. It is possible, of course, that hybrids of Bison by common blue were over-

TABLE 2.—*Natural crossing in seven varieties of flax grown at St. Paul, Minn. and Mandan, N. D., 1931-33.*

Variety	Total number of plants examined and number of hybrids found*									
	St. Paul					Mandan				
	1931		1932		1933		1931		1932	
	Total	Hybrid	Total	Hybrid	Total	Hybrid	Total	Hybrid	Total	Hybrid
Blanc.....	222	1	252	5	224	3	300	3	458	23
Indian Type 68....	207	0	190	2	270	0	300	1	419	1
Pale Malabrigo....	205	3	228	6	80	2	300	1	460	7
Crimped White....	315	0	462	8	154	0	300	0	530	8
Tall Pink.....	223	0	493	0	238	2	300	0	428	8
Ottawa 770B.....	246	0	132	3	52	1	300	0	340	8
Bison.....	1,000	0	1,500	0	1,000	0	1,500	0	2,000	0
Variety	Percentage of natural crossing									
	St. Paul					Mandan				
	1931		1932		1933		1931		1932	
	Av.	1933	Av.	1931	1932	1933	Av.	1933	Av.	General average
Blanc.....	0.45	1.98	1.34	1.26	1.00	1.50	2.51	1.88		
Indian Type 68....	0.00	1.05	0.00	0.35	0.33	0.25	0.27	0.31		
Pale Malabrigo....	1.46	2.63	2.50	2.20	0.33	0.75	0.87	1.53		
Crimped White....	0.00	1.73	0.00	0.58	0.00	0.50	0.67	0.62		
Tall Pink.....	0.00	0.00	0.84	0.28	0.00	1.87	0.71	0.49		
Ottawa 770B.....	0.00	2.27	1.92	1.40	0.00	0.00	0.78	1.09		
Bison.....	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		

\*The results in 1931 represent the natural crossing that occurred at Bozenan, Mont., in 1930, where the seed was grown in a nursery of 200 or more varieties and strains. At Mandan the total number of plants grown in 1931 and 1933 were estimated; in all other cases the number were counted.

looked, as the  $F_1$  plants would be difficult to recognize. It is certain, however, that the Bison variety is still remarkably pure after 15 years of cropping since its introduction. The anthers of the Bison flower entirely surround the stigma and pollen is so abundant that self-pollination is almost assured.

The results indicate that the percentage of natural crossing in flax differs in different varieties and in different seasons. The kind and abundance of insects probably determine chiefly the extent of crossing in varieties which, for any reason, are not completely self-pollinated. Thrips are nearly always present on flax flowers, but it seems doubtful if they are important in causing cross-pollination in flax, as suggested by Henry and Tu (2). They usually are present on bagged flowers as well as on those left uncovered. Honey bees and bumble bees often visit flax flowers and may carry pollen from plant to plant. There is also the possibility that the pollen may be blown short distances when it dries and falls from the anthers.

In selecting new varieties, perhaps the flax breeder should consider the type of flower with regard to abundance of pollen and the manner in which the anthers surround and over-top the stigma. A type of flower such as is found in Bison flax will assure a high degree of self-pollination.

The observations on the time of pollination and the simple experiments on the time of fertilization indicate that when normal pollination occurs there is little chance for outcrossing to occur. It is probable that outcrossing can occur only when there is some deficiency of anthers or pollen, or when the stigma is exerted beyond the anthers, or when hot, dry weather injures the pollen. The writer has considerable data to show that such varieties as Bison, Linota, and Redwing have a higher degree of fertility (more seeds per boll) in hot, dry weather than the large-flowered varieties such as Rio, Walsh, and others of this type. This is probably because the pollen and stigma of the larger flower is more exposed to the drying effect of sun and wind than is the smaller funnelform flower. It is notable, also, that the tubular flower of Indian Type 68 is remarkably self-fertile under such adverse weather conditions.

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## BREEDING RYE BY CONTINUOUS SELECTION<sup>1</sup>

HOWARD B. SPRAGUE<sup>2</sup>

ALTHOUGH satisfactory breeding systems have been devised for crops that are largely cross-pollinated, such as corn, and those that are largely self-pollinated, such as wheat, oats, barley, etc., there is considerable divergence of opinion as to the most satisfactory method of breeding for the improvement of partly cross-pollinated crops. In fact, reliable estimates as to the degree of cross-pollination are wanting for most crops falling in the latter group. Obviously, it is necessary to have some approximate values on the amount of natural crossing and the consequent degree of heterozygosity in order that breeding systems may be given the proper theoretical treatment from the standpoint of genetics.

Rye (*Secale cereale*) is listed by Hayes and Garber<sup>3</sup> as a naturally cross-pollinated plant. Quoting various investigators, rye flowers are reported to be so constructed that it is difficult, if not actually impossible, for the pollen to fall on stigma of the same flower. Evidence is also given supporting the view that "the rye flower is self-sterile, but that the spikelet is not necessarily so". Heribert-Nilsson using a waxless type of rye plant as an indicator, observed cross-pollination to the extent of 37.3% to 54.4% when separated 60 meters from fields of normal plants. Other evidence is cited to indicate that self-fertilized florets are capable of producing seed, at least in some strains.

In view of the modern conception of the genetic causes of self-sterility in cross-pollinated species, it seemed worthwhile to re-investigate the extent to which cross-pollination occurs in other strains of rye than those used by European workers. A preliminary study indicated that, although self-pollination of florets might occur to a considerable degree with normal plants, pollen from other plants must account for a considerable part of fertilized flowers, even though the capacity for self-fertility prevails. The possibility of crossing between flowers of the same spike, or between flowers of different spikes on the same plant, which are genetically identical with self-pollination, also seemed to indicate the possibility of an appreciable amount of selfing with this crop.

On the basis of a substantial degree of self-pollination, continuous selection of superior plants in open-pollinated lines should gradually concentrate the genetic factors responsible for higher yields and permit gradual elimination of non-adaptive traits. This process should be more rapid when crossing is limited to strains of equal duration in the breeding nursery. In view of the continuous outcrossing, there would

<sup>1</sup>Contribution from the Department of Agronomy, New Jersey Agricultural Experiment Station, New Brunswick, N. J. Journal series paper, New Jersey Agricultural Experiment Station, department of Agronomy. Received for publication December 24, 1938.

<sup>2</sup>Agronomist.

<sup>3</sup>HAYES, H. K., and GARBER, R. J. *Breeding Crop Plants*. Ed. 2, New York: McGraw-Hill Book Co. 1927.



seem to be a much smaller chance of losing any favorable genes by segregation and elimination than might be expected for a breeding system in which inbreeding and development of stable lines plays an important part. Since no hand pollinations are involved in the program of continuous selection in open-pollinated lines, a large number of strains may be carried without undue expense or labor. In addition it may be assumed that superior strains developed by this method could be recombined at any stage in the breeding program without appreciable loss of yielding ability in the subsequent generations. Thus, the improved new variety could be maintained by the ordinary procedures to prevent mixing or hybridization with other strains.

#### SELECTION AT NEW JERSEY

The possibilities of rather rapid improvement by the time-honored methods of selection influenced the choice of this means of rye breeding at New Jersey. In order that the genetic constitution of the original stocks be as varied as possible, the following varieties were combined at the beginning of the program: Rosen (Michigan), Wisconsin Pedigree No. 2 (Wisconsin), Swedish (Minnesota), Abruzzi (Virginia), common (New York), and five sources of common rye from different portions of New Jersey. After two years, a total of 216 superior plants was chosen from a space-planted plot and these were treated as individual strains beginning with the nursery planted in September 1927. Each strain was space planted, 3 to 4 inches between plants, in rows 1 foot apart and 16 feet long. At maturity, one to two erect plants in each line which appeared to be more productive of grain and straw than others in that row were chosen to propagate the next generation. Selections were made annually by the writer to insure continuity in types chosen. Preference was given to outstanding plants with no better than equal opportunity in space and position. Care was taken in placement of the breeding nursery each year to obviate the possibility of cross-pollination by unselected rye.

In addition to the breeding nursery each selection was tested for yielding ability, using the seed remnant not required for space planting. In view of the limited seed supply, yield test plots were necessarily small and no replication was possible. Each strain was tested in an 8-foot row, with rows 1 foot apart. Every sixth row was planted to New Jersey common rye. The seeding rate of all selections was 6 pecks per acre. Yield tests of the entire nursery of 216 strains were harvested in 1929 for the first time and have been continued annually through 1937. For comparisons, all yields were calculated in percentage of the nearest check plots.

#### OBSERVATIONS ON DEGREE OF CROSS-POLLINATION

In view of the special significance attached to the amount of crossing in this system of breeding, a test was made in the season of 1930-1931, using Wisconsin Pedigree No. 6 rye which is practically pure for colorless kernels, and Rosen rye with greenish purple kernel color. A block of 10 rows of Wisconsin Pedigree No. 6 (Imperial) was planted with the rows 20 feet long and 1 foot apart. A similar block

of 10 rows of Rosen rye was planted on one side of the Wisconsin Pedigree plat. At harvest time, each row of Wisconsin Pedigree was harvested and threshed separately and the percentage of kernels showing the effect of pollination with Rosen rye determined. A similar test was conducted in 1936-37. The planting plan is given in Fig. 1 and the results are shown in Table 1.

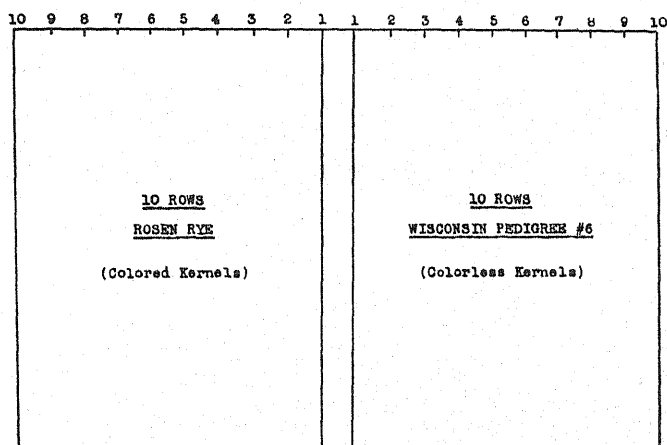


FIG. 1.—Planting plan to test the percentage of natural cross-pollination in rye as measured by xenia. The rows were 20 feet long and 1 foot apart; seeded at 6-peck rate in late September.

TABLE 1.—Percentage of cross-pollination between Wisconsin Pedigree No. 6 White Rye (♀) and Rosen colored rye (♂), as measured by xenia, New Brunswick, New Jersey.\*

Distance of White Rye from Rosen, feet	Cross pollination, %			Total crossing from both directions %
	Season of 1931	Season of 1937	Average	
1.....	29.9	20.3	25.1	50.2
2.....	24.2	15.8	20.0	40.0
3.....	21.1	12.3	16.7	33.4
4.....	17.4	9.7	13.5	27.0
5.....	9.1	7.7	8.4	16.8
6.....	7.2	6.7	6.9	13.8
7.....	7.6	6.9	7.2	14.4
8.....	8.2	6.4	7.3	14.6
9.....	4.8	6.9	5.8	11.6
10.....	3.7	4.5	4.1	8.2

\*Rows planted in a Northwest to Southeast direction.

It is clear that in contiguous rows, cross-pollination, as measured by xenia, did not greatly exceed 50% in these tests. No account has been taken of the amount of foreign pollen provided by plants in the same row, but it seems unlikely that this would greatly increase the total. Xenia decreased at a rather uniform rate with increasing distance, reaching the low value of 8% at 10 feet. Doubtless pollen would

be carried by wind for much greater distances across open areas and in regions with strong winds at time of pollination. The average wind velocity in May and June at New Brunswick is approximately 10 miles per hour, with considerable variation from hour to hour and day to day. In a breeding nursery, the distance traveled should approximate that found in these tests.

Using 50% as the normal amount of cross-pollination occurring in the breeding nursery, the choice of a single plant accounts for three-quarters of the total inheritance, one-half coming through the female gametes of the mother plant and one-quarter from the male gametes of the same plant. Since outcrossing apparently accounts for one-quarter of the total inheritance, there is opportunity for a constant infusion of "new blood" from the other selected strains in the nursery. Improvement would be accomplished by gradually raising the productivity of the entire breeding nursery, but the possibility exists of obtaining superior blocks or groups of strains, since the bulk of the foreign pollen comes from distances no greater than 10 feet.

#### STABILITY OF A RECONSTITUTED VARIETY

In 1933, 98 strains were chosen as superior on the basis of yield tests conducted in 1931-32 and 1932-33. Since the seed remnants used in planting the above tests were inadequate for the purpose, seed from selected plants of the same strains in the 1933 crop were bulked and planted in an isolated field for increase in 1933-34 and 1934-35. With the seed so provided, the new variety was released for further testing in 1935-36 and 1936-37 under the name of "Raritan" rye.

It should be noted that the average yield of these 98 strains for the two years of individual yield tests was 130.4% of the unselected common rye. Raritan rye has since been found to exceed common rye by about 10%. This figure is of the same order as the average yield of all 216 strains for 1932 and 1933 and not that of the 98 selections. Apparently no superiority of individual lines had yet been established when the 98 selections were chosen and the new variety merely represented the increased vigor of the entire nursery.

One of the prime considerations was the determination of the stability of the new variety. In 1936, trials were conducted with the original blended seed from the 1933 crop and seed of the two subsequent generations. Each seed lot was grown in nine plats in comparison with common rye, using the seeding rate of 6 pecks per acre. The individual plats were 12 feet long and 3 feet wide. The germination had dropped to 78% on the 1933 seed lot, and to compensate for this a heavier seeding rate was used. The yields of grain and straw for the three different generations of Raritan rye are shown in comparison with common rye in Table 2. Although the first generation seems somewhat superior to the parental blend and to the second generation, such behavior may be explained by chance fluctuations and by incomplete compensation for the low germination of the oldest seed lot.

A further test of the stability of Raritan rye is provided by the regular yield tests in comparison with New Jersey common and Rosen, the results of which are given in Table 3. The varietal tests

TABLE 2.—*The stability of a new rye variety created by combining 97 related selections as measured by growth tests in the year 1935-36.\**

Generation	Average height of plant, in.	Straw yield per acre, lbs.	Grain yield per acre, bu.
Raritan rye:			
1933 seed, parental blend of 97 strains . . . . .	54.3	5,370	46.0
1st generation, 1934 seed . . . . .	54.6	5,892	50.1
2nd generation, 1935 seed . . . . .	53.9	5,773	48.8
Common unselected rye . . . . .	53.4	5,328	45.6

\*Average of nine plats per seed lot; seeding rate adjusted to provide 6 pecks per acre of seed germinating 90%. 1933 seed germinated 78% when seeded in September 1935.

TABLE 3.—*Performance of Raritan rye from the second to fourth year after its creation by combination of 97 related selections.*

Variety	Straw yield per acre, lbs.*				Grain yield per acre, bu.*			
	1935	1936	1937	3-year average	1935	1936	1937	3-year average
Rosen . . . . .	6,873	5,208	3,869	5,317	55.1	48.1	27.7	43.6
N. J. common . . . . .	7,481	5,987	3,841	5,770	52.9	52.0	25.0	43.3
Raritan . . . . .	7,545	6,484	4,161	6,063	57.9	55.6	30.9	48.1
Increase of Raritan over N. J. common, % . . . .	0.9	8.3	8.3	5.1	9.4	6.9	23.6	11.1

\*Average of 10 nursery plats per variety, plats 16 feet long and 36 inches (five drill rows) wide trimmed at harvest to 12 feet by 21 inches.

were planted with a grain drill in rows approximately 7 inches apart, at a 6-peck rate. Each variety appeared in 10 systematically distributed plats, 16 feet long and 36 inches (five drill rows) wide. The plats were trimmed at harvest time to 12 feet by 21 inches (three drill rows). The 1935 comparison indicates the yielding ability of the first generation after combination of the 98 lines, 1936 the second, and 1937 the third generation.

These three tests support the assumption that lines produced by continuous selection of outstanding plants with open-pollination are comparatively stable when combined. The fluctuations in relative yields of Raritan indicate no recession in vigor or adaptation; merely the differential response of the new variety to changes in the environment.

#### PROGRESSIVE CHANGES IN VIGOR OF STRAINS

It was recognized that Raritan rye had been produced after a comparatively short period of selection. To test whether any further increase in vigor might have resulted from continued selection, the yields of individual strains for the crop years ending in 1935, 1936, and 1937 were examined. Eliminating from consideration all strains which had failed to be consistently high in grain yield during the

3-year period and which had failed to average 20% or more grain than the unselected check variety, a total of 95 strains remained. The average increase in yield of these strains for the 3-year period was 44.7% in contrast with 30.4% increase for the most productive 98 strains in the test period four years earlier. An important point is that 57 selections are found in both groups, supporting the belief that this breeding method permits the development of superior blocks or groups of strains because of the rather limited horizontal distribution of pollen.

Some further evidence on progressive changes in yielding ability of the breeding nursery is provided by the average yield of all 216 strains for the years 1932 and 1933 in contrast with the years 1935-37, inclusive (Table 4). Using averages to compensate for annual fluctua-

TABLE 4.—Average grain yield of 216 rye selections in terms of unselected common rye.

Year grown	Percentage yield of 216 selections	Grain yield of unselected common rye, bu.
1932.....	97.9	27.6
1933.....	127.0	31.7
2 year av.....	112.4	29.6
1935.....	111.7	52.9
1936.....	123.4	52.0
1937.....	156.7	25.0
3-year av.....	130.6	43.3

tions, it seems probable that the difference between 112.4% for the first period is significantly lower than that of 130.6% for the latter period. An additional test of this breeding method will be provided during the next three years by the performance of the new variety produced by combining 1937 seed of the 95 strains which showed superiority from 1935 to 1937.

#### DISCUSSION

The evidence given by these tests supports the assumption that rye is a partly cross-pollinated species and that considerable general improvement may be achieved by continuous selection of superior plants with open pollination. The stability of a mass variety produced by combining a large number of lines similarly selected is significant from the standpoint of practical utilization of the breeding product. Although considerable time seems to be necessary to achieve outstanding superiority, the results suggest that the number of generations is no greater and perhaps less than would be required by the inbreeding and recombination system.

There are several limitations to this system of breeding. For species that approach complete cross-pollination, such selection should not be expected to produce any more favorable results than has been found for corn. It should also be observed that characters cannot be accu-

mulated or concentrated unless present in the breeding nursery. Consequently, there would be a great advantage in beginning the breeding nursery with a wide range of types and by including such specific characteristics as are known or suspected to be advantageous. Moreover, this method of breeding gives no information on the inheritance of specific characters or genes. Also, the final product, a commercial variety, will show much greater variability than one developed by inbreeding and isolation of purified lines.

To compensate for the limitations of this breeding method, there is the greater assurance that favorable factors will not be lost by segregation and elimination and that strains may be combined for commercial use without loss of vigor in subsequent generations. In addition, a large breeding nursery may be maintained with a relatively small amount of labor and personal attention. Plant breeders whose responsibilities cover a considerable number of species may be able to produce substantial improvement of partly cross-pollinated species without requiring a large staff of skilled assistants. It seems likely that many forage plants will fall in the category of partly cross-pollinated species, and thus be favorable objects for this system of improvement.

#### SUMMARY

Rye is apparently partly cross-pollinated to the extent of approximately 50%, judging by the amount of xenia evident in a colorless kernalled variety of rye growing adjacent to a colored kernalled variety. Less than 10% of the foreign pollen was effective at a distance of 10 feet under comparatively normal conditions.

A total of 216 strains were selected from a mass variety containing 10 varieties and strains after two years of natural crossing. Each of the 216 lines was continued from 1928 through 1937 by selection of superior plants in space-planted rows with open-pollination permitted between all lines in the breeding nursery. Parallel tests of yielding ability were made for all lines, using solid rows, with unselected common rye as the check.

After five years of selection, 98 lines were chosen for 1933-34 on the basis of yield performance during the previous two years, and these were combined to form a new variety named Raritan. Raritan proved to be stable in yielding ability in subsequent generations, exceeding common rye by 10% to 12% in grain yield.

Further improvement in productivity by continued selection within each of the 216 lines for the four years ending in 1937 is indicated by the yielding ability of the best 95 lines and by that of the entire breeding nursery.

The limitations and advantages of this system of breeding are briefly discussed. Gradual concentration of desirable traits, and elimination of non-adaptive characters is provided without danger of losing valuable genes as usually occurs with inbreeding. The system requires relatively little time and skilled aid, but furnishes no information on inheritance of specific factors.

## EXPERIMENTS ON ARTIFICIAL HYBRIDIZATION OF RICE<sup>1</sup>

N. E. JODON<sup>2</sup>

RICE is an attractive crop for genetic studies, displaying fully as many variations as any other of the small grains. The scope of plant breeding and genetic investigation with rice might be enlarged if a rapid and effective method of controlled pollination were available. The hybridization technic described by Jones (5)<sup>3</sup> is widely used and sufficient hybrid seed may be obtained for the usual studies of segregating populations, but the seed set is too low for extensive backcrossing or studies requiring large numbers of crossed seeds.

### REVIEW OF LITERATURE

#### BLOOMING

The literature on pollination and blooming in rice up to 1929 has been reviewed by Jones (6). Adair (1) made an extensive study on blooming in rice in Arkansas, and Laude and Stansel (7) made observations in Texas under conditions nearly identical with those under which the data here reported were obtained. The writer has tabulated no data on blooming but his general observations are, with some exceptions, in agreement with the results reported for Texas and Arkansas.

The peak of blooming at Crowley, La., in seasonable weather in August and early September when most varieties are at the blooming stage appears to occur between 10:00 and 11:00 a.m. rather than between 11:00 a.m. and noon as reported by Adair (1) and by Laude and Stansel (7). The departure from the behavior in Arkansas may be due to temperature differences. The difference from results obtained in Texas may be due to observing different varieties. Adair suggests that pollen may be shed before the florets open, but the writer's observations indicate that exposure to the open air is normally necessary for dehiscence of the anthers. Laude and Stansel stated that rice florets may remain open from 42 minutes to over 2 hours. The writer found that at Crowley the florets usually opened and closed within an hour or less.

Temperature, as suggested by Adair (1) and by Jones (6), probably is the most important factor influencing the time of blooming in rice. These workers noted differences among varieties in the time of initial daily blooming and the writer has observed differences of as much as 2 hours. No explanation of such varietal differences has been found in the literature, but the writer has observed that varieties having long slender glumes appear to bloom earliest. A slight swelling of the lodicule will open long narrow glumes to a sufficient angle to expose the anthers at the tip of the floret. Short and relatively wide glumes must be spread at a wider angle to expose the anthers, hence more time may be required for the lodicule to swell sufficiently to open the floret fully.

<sup>1</sup>Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, in cooperation with the Louisiana Experiment Station. Experiments conducted at the Rice Experiment Station, Crowley, La. Received for publication December 30, 1937.

<sup>2</sup>Assistant agronomist.

<sup>3</sup>Figures in parenthesis refer to "Literature Cited," page 305.

## ARTIFICIAL POLLINATION

The method of crossing used by Jones (5) in California, which will be referred to here as the clipping method, involves emasculation by removal of anthers with tweezers through a slanting opening made by clipping away a portion of the upper part of the lemma. This is done in the evening or morning prior to normal blooming and before the anthers have reached the stage where they will shed pollen on handling. When the clipping method was used in Louisiana, the crossed seeds were imperfectly developed and germination low.

Pollination is accomplished by breaking mature anthers within the emasculated floret. Mature anthers may be obtained from florets in which the elongating filaments have pushed the anthers towards the apex of the unopened glumes. Such anthers ripen rapidly after the glumes are forced open, changing from a dark yellow color and firm consistency to a lighter yellow color and a mealy texture as the pollen grains separate within the anther sack and burst readily on handling. This method of obtaining pollen was followed in making all crosses reported herein.

The application of collected pollen with a flattened needle as described by Florell (3) for wheat was unsuccessful because of the humid conditions in the rice field. Rice pollen appears to be viable for only a brief period. Mechanical stimulation as used by Florell to hasten anthesis of wheat for the collection of pollen was not effective in rice.

Van der Meulen (8) in Java applied to rice the suction method of emasculation developed by Kirk with satisfactory results by either clipping off part of the glume or by using early opening florets which had not shed pollen. In all varieties used in the studies by the writer at Crowley pollen was shed before the florets opened enough to permit removal of anthers, except when the temperature was unseasonably low.

Ramiah, as reported by Dumont (2), found that increasing the temperature artificially hastened the opening of the glumes. He reported that the heat absorbed by panicles covered with a black paper bag raised the temperature sufficiently to induce blooming. The anthers of such florets do not dehisce immediately and may be removed without injury to other parts of the floret. The writer, however, failed to obtain satisfactory opening of florets by this means under Louisiana conditions.

Poggendorff (10) also attempted the use of black paper bags to hasten opening but found that anthers often burst upon their removal from the florets. He found, however, that on humid days anthers may be removed from the naturally opening florets before dehiscence. Poggendorff obtained pollen from panicles floated on water, the temperature of which hastened the development of the anthers to the point where they burst on handling. He was "usually 100% successful" in obtaining crosses.

Mulimbayan (9) has compared the clipping method with a method in which mechanical stimulation was used to open the glumes, after which the anthers are removed without injury to the floret. The clipping method was more rapid and gave the better results, but anther sacks were sometimes clipped and the pollen scattered. This difficulty was not encountered in Louisiana.

A method of emasculating sorghum by means of heat was developed by Stephens and Quinby (12). A container was fitted around the sorghum head filled with water at an initial temperature of 44° C, and allowed to remain 10 minutes. The viability of the pollen was destroyed without injury to other flora



organs. This method appeared to be adaptable to rice and the writer's results with it are reported herein.

Suneson (13) found anther sterility in wheat to be induced by temperatures of 27° to 36° F. Some or all florets opened on spikes emerging from the boot one to five weeks after exposure to temperatures within this range were self sterile. Self-sterile florets were easily distinguished since they remained open and cross pollinations were successful. The writer tested the effect of low temperatures on rice flowers in 1936.

## PROCEDURE AND RESULTS

### INJURY DUE TO MANIPULATION

An experiment was conducted to obtain information on the extent of injury caused by clipping and bagging rice florets in which the lemma, palea, or both, were clipped. The anthers were not removed. The method used by Jones (5) was followed in clipping the lemma. The smaller size and the relative position of the palea required the removal of a proportionately greater part of this organ in making an opening large enough to permit the insertion of tweezers. When both the lemma and palea were clipped, the cut was made in much the same way as when the lemma alone was clipped, but the angle of the cut was changed to include a part of the palea. The panicles were clipped or bagged early in the morning or in the late afternoon. From one-fourth to one-half the florets on the panicles used probably would have opened the day they were chosen or the following morning. Florets that had bloomed previously were removed. Some of the panicles were covered with glassine bags and others were left uncovered. Two rather dissimilar varieties, Fortuna and Early Prolific, were used. The results are summarized in Table 1.

There were no consistent differences in seed set following different methods of clipping when the panicles were bagged. The lowest set within Fortuna was obtained when the palea was clipped, but this did not occur in the Early Prolific variety.

The unbagged clipped panicles gave a lower seed set than did those that were bagged. This probably was due chiefly to extrusion and failure of dehiscence of the immature anthers and to desiccation of the stigma and palea. Exposure to insects and fungus organisms may also have been factors. The lowest seed set resulted from clipping the palea and nearly as much sterility followed clipping both glumes.

The results of clipping the lemma in the morning and late afternoon also are given in Table 1. While differences were found, they were not consistent since a lower seed set was obtained in Fortuna from afternoon and in Early Prolific from morning clipping.

Bagging alone, when done in the morning, reduced the seed set to about that of the bagged clipped panicles. Handling and increased temperature within the bag perhaps caused the florets to open prematurely, and be followed by extrusion and imperfect dehiscence of anthers with a resulting incomplete pollination. Bags placed on the panicles in the evening had less effect on the seed set. Fortuna panicles bagged in the evening gave practically a normal seed set, while Early Prolific showed some reduction.

TABLE 1.—*Effect of clipping glumes and bagging panicles on the percentage of seed set in Fortuna and Early Prolific rice.*

Organ clipped	Time	Panicles bagged				Panicles not bagged			
		Pan- icles, No.	Flor- ets, No.	Seed, No.	Set, %	Pan- icles, No.	Flor- ets, No.	Seed, No.	Set, %
Fortuna									
Lemma.....	A.M.	6	625	456	73.0	5	644	240	37.3
Lemma.....	P.M.	4	335	226	67.5	4	299	109	36.5
Palea*.....	—	4	382	196	51.3	5	328	53	16.2
Both glumes*	—	4	338	220	65.1	5	437	85	19.5
None.....	A.M.	5	944	644	68.2	5	959	816	85.1
None.....	P.M.	4	829	709	85.5	4	806	712	88.3
Early Prolific									
Lemma.....	A.M.	7	603	242	40.1	4	285†	31	10.9
Lemma.....	P.M.	4	313	175	55.9	6	435	135	31.0
Palea*.....	—	4	261	130	49.8	4	281	8	2.8
Both glumes*	—	4	258	145	56.2	4	246	16	6.5
None.....	A.M.	7	852	392	46.0	4	434†	383	88.2
None.....	P.M.	4	521	333	63.9	7	913	772	84.6

\*1934 only; other data are combined results from 1934 and 1936.

†1936 only.

## RELATION OF TEMPERATURES TO SEED SET

The success of Stephens and Quinby in the use of hot water for bulk emasculation of sorghum flowers suggested the possibility of adopting this method for rice. The application to rice was simple in contrast to the difficulty of fitting a water-tight container around the stalk below a head of sorghum. Rice culms were merely bent over and the panicles inserted in a small-mouthed quart-size thermos bottle. A trough-like holder for the thermos bottle, mounted on two spreading legs in front and a shorter one behind, was devised. The legs were pointed so that the holder could be set firmly in the mud at any angle necessary to permit immersion of the panicles without spilling the water.

All tests were made in the field. The temperatures used ranged from 50° C down to 0° C, and the duration of treatment varied from 2 to 25 minutes. The majority of the treatments were of about 10-minute durations. The first tests were made in 1934 and the results are shown in Table 2.

A valuable immediate result of the tests was the discovery that treatments made during the morning, prior to natural blooming, cause the florets to open in response to the stimulus of the sudden change of temperature. Opening takes place promptly except when the temperature of the water used was not more than 3 or 4 degrees above or below the air temperature. This prompt opening eliminates the necessity of clipping the glumes to get access to the anthers and stigma.

Panicles used were ordinarily about two-thirds exserted from the boot. At this stage the greatest number of florets are ready to bloom

TABLE 2.—Effect of immersion of rice panicles in water at temperatures from 0° to 51° C on the viability of the pollen.

Year	Treatment		Varieties, No.	Panicles			Florets opened, No.	Grains obtained, No.	Seed set, %
	Temperature, °C	Duration, min.		Treated, No.	Setting one or more grains, No.	Panicles, %			
1936-37	0° -3°	5-10	5	9	3	33.3	207	6	2.9
1937	4°	10	6	9	4	44.4	287	14	4.9
1936-37	5°	10-20	6	10	4	40.0	286	18	6.3
1936-37	6°	7-10	6	9	5	55.6	344	34	9.9
1936-37	8°	6-12	4	7	7	100.0	183	70	38.3
1936-37	9° -11°	6-13	3	6	6	100.0	195	145	74.4
1936	12° -19°	5-10	3	3	3	100.0	70	21	30.0
1936	20° -39°	10	3	12	12	100.0	351	219	62.4
1935	42° -44°	10-25	7	22	1	4.5	545	1	0.2
1936	40° -44°	10-12	5	20	0	0.0	521	0	0.0
1936	42° -44°	2-6	5	22	7	31.8	907	41	4.5
1936	43° -44°	10*	2	3	2	66.7	27	2	7.4
1937	43°	10*	1	1	1	100.0	17	14	82.4
1936	40° -42°	10†	5	12	10	83.3	158	95	60.1
1936	42° -44°	10†	5	11	5	45.5	122	5	4.1
1936	44° -46°	10†	1	2	2	100.0	8	4	50.0
1936	45° -47½°	10	2	9	0	0.0	161	0	0.0
1936	47½° -51°	10	3	10	0	0.0	0	0	0.0
1936	Check, not covered†		2	11	11	100.0	1,692	1,549	91.5
1936	Check, covered†		2	13	13	100.0	2,284	1,578	69.1

\*Treated while florets were open and after anthers debised.

†Afternoon treatments; florets opened following morning.

‡Adapted from data in Table 1.

on a given day and consequently the greatest number opened in response to treatment. Mature florets which had bloomed previously and immature florets which did not open were removed and the panicles covered with glassine bags until after the glumes were closed. When treatments were made one to two hours prior to the beginning of natural blooming, opening sometimes began before the panicle was removed from the water. All florets which responded were usually beginning to open within a half hour after treatment. Varietal differences were observed in the time required for florets to open. Response was slow on cool mornings.

Temperatures of  $47^{\circ}\text{C}$  or higher resulted in the death of the entire panicle and of any portion of the flag leaf that also happened to be immersed in the hot water. Florets usually failed to open at this temperature. Anthers became watery in appearance and did not dehisce. Slight injury was indicated by bleaching of the chlorophyll at temperatures as low as  $43\frac{1}{2}^{\circ}\text{C}$ , while some panicles showed no appreciable injury at  $45^{\circ}\text{C}$ .

Panicles treated at various temperatures are shown in Fig. 1.

Within the temperature range of  $40^{\circ}$  to  $44^{\circ}$  florets opened promptly and normally. The anthers dehisced normally and the stigmas were usually dusted with pollen. It will be noted from Table 2 that from over 1,000 florets opening in response to treatments of 10 minutes or more at  $40^{\circ}$  to  $44^{\circ}$  only one seed was formed. Temperatures within this range are shown by these results to destroy the viability of the pollen effectively.

Florets on panicles treated in the afternoon at  $40^{\circ}$  to  $44^{\circ}$  did not open until the next morning. Nevertheless, opening took place earlier in the morning than normal blooming. Afternoon treatments at  $42^{\circ}$  to  $44^{\circ}$  destroyed the pollen more effectively than treatments at  $40^{\circ}$  to  $42^{\circ}$ . Most florets failed to open when treated at temperatures above  $44^{\circ}$ .

Treatments made at  $43^{\circ}$  to  $44^{\circ}$  approximately one-half hour after normal blooming had begun, after stigmas were well dusted with pollen and while the florets were still fully open, did not prevent fertilization of the ovary. This suggests that possibly the pollen had germinated and the male gametes had entered the pollen tube prior to treatment. Pope (11) reports that in barley pollen had germinated within 5 minutes after reaching the stigma and that within 10 minutes the male gametes had entered the pollen tube. Treatments made 24 hours after pollination were entirely without effect on seed set.

Low and intermediate temperatures were also tested. The percentage of seed set was low after treatment at temperatures of  $0^{\circ}$  to  $8^{\circ}\text{C}$ . Treatments at  $0^{\circ}$  to  $3^{\circ}\text{C}$  for 10 minutes probably would be effective for emasculation. No injury was noted, but the higher range for use in making crosses is preferred as the florets usually open somewhat more promptly.

Temperatures ranging from  $9^{\circ}$  to  $39^{\circ}\text{C}$  had little effect on the percentage of seed set. Collecting pollen in quantities for mass pollination from florets opened by temperature treatments not injurious to pollen does not appear feasible because the anthers from such florets do not



FIG. 1.—Pollen was unviable in rice florets that opened in upper part of panicles in response to high ( $40^{\circ}$ – $44\frac{1}{2}^{\circ}$  C) and low ( $0^{\circ}$ – $4\frac{1}{2}^{\circ}$  C) temperatures. Little or no other injury occurred at  $44\frac{1}{2}^{\circ}$  C or lower. Some seed developed following treatment at  $39^{\circ}$  C but not at  $40^{\circ}$  C.

dehisce readily and rice pollen becomes sticky and useless almost immediately upon exposure to moist air.

#### EFFECT OF METHOD OF EMASCULATION UPON SEED SET

The result of cross pollinations following emasculation by clipping and the hot and cold water methods are given in Table 3. Jones' method of obtaining and applying pollen was followed. Varieties differing in length of growing season were brought into flower simultaneously by planting on different dates, as suggested by Jenkins (4), or

TABLE 3.—Comparison of artificial pollination of rice emasculated by three methods.

Year	Method of emasculation	Varieties used, No.	Panicles total, No.	Setting one or more grains		Florets, No.	Seed set		Non-crosses, No.	F <sub>1</sub> plants matured, No.	Percentage F <sub>1</sub> plants matured on basis of	
				Number	%		Number	%			Florets pollinated	Supportedly crossed grains
1934	Clipping	21	159	113	71.1	1,458	379	26.0	26	208	14.3	54.9
1935	Clipping	14	38	20	52.6	390	72	18.5	5	19	4.9	26.4
1936	Clipping (includes all)	13	24	18	75.0	279	109	39.1	4	39	14.0	35.6
1935	Hot water (exclusive of backcross)	15	28	25	89.3	478	167	34.9	4	137	28.7	82.0
1936	Hot water (includes all)	24	73	67	91.8	1,347	572	42.5	5	403	29.9	70.5
1935	Hot water (backcross)	1	14	8	57.1	282	14	5.0	1	13	4.6	92.9
1936	Hot water (backcross)	1	8	8	100.0	340	141	41.5	0	133	39.1	94.3
1936	Clipping (glutinous) } Paired	4	5	5	100.0	56	31	55.4*	0†	14	25.0	45.1
1936	Hot water (glutinous) } Paired	4	5	5	100.0	71	52	73.2*	1†	20	28.2	38.5
1936	Clipping (non-glutinous) } Paired	7	10	6	60.0	112	31	27.7	0	13	11.6	41.9
1936	Hot water (non-glutinous) }	7	10	10	100.0	110	56	50.9	0	49	44.5	87.5
1934-36	Clipping, total	36	221	151	68.3	2,127	560	26.3	35	266	12.5	47.5
1935-36	Hot water, total	35	115	100	87.0	2,107	753	35.7	10	553	26.2	73.4
1937	Hot water (includes all)	34	122	111	91.0	2,526	1,221	48.3	—	—	—	—
1937	Hot water } Paired	10	17	15	88.2	264	125	47.3	—	—	—	—
1937	Cold water	10	17	16	94.1	242	80	33.1	—	—	—	—

†Hodine test.

\*Percentage crossed grains.



FIG. 1.—Pollen was unviable in rice florets that opened in upper part of panicles in response to high ( $40^{\circ}$ – $44\frac{1}{2}^{\circ}$  C) and low ( $0^{\circ}$ – $4\frac{1}{2}^{\circ}$  C) temperatures. Little or no other injury occurred at  $44\frac{1}{2}^{\circ}$  C or lower. Some seed developed following treatment at  $39^{\circ}$  C but not at  $40^{\circ}$  C.

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\*Percentage crossed grains.

†Hodine test.



by short-day treatments of late varieties. Attempts to develop more rapid methods of pollination failed.

An initial temperature of about  $43\frac{1}{2}^{\circ}$  to  $44^{\circ}$  C was used for the hot water treatments. The temperature was lowered during the 10-minute treatment about  $0.5^{\circ}$  C for each panicle immersed in the bottle. Thus three or even four panicles could be treated in the same water without cooling the water too much. This was the number ordinarily pollinated during one morning. Cold water emasculation was accomplished by 10-minute treatments at about  $1^{\circ}$  to  $4^{\circ}$  C. The results of the pollinations are given in Table 3, and pollinated panicles are shown in Fig. 2.

In 1935 the clipping method gave only 18.5% seed set, although if eight panicles lacking in vigor that failed to set seed are excluded the percentage becomes 23.2, while the hot water method gave a seed set of 34.9%.

In 1936 similar panicles were selected in pairs, emasculated by the clipping and hot water methods, and pollinated. The glutinous varieties were recorded separately since at Crowley they usually give a higher seed set than the non-glutinous varieties. A seed set of 55.4% was obtained by the clipping method and 73.2% by the hot water method in the glutinous varieties. With the non-glutinous varieties a 27.7% set was obtained by the clipping method and 50.9% by the hot water method. Comparing all pollinations made by the two methods in 1936, a difference of only 3.4% was found in favor of the hot water method. The paired panicles, however, probably give a truer comparison of the relative success of the methods because of the large proportion of glutinous panicles among those clipped.

Since the season did not appear to have any influence on the success of pollination, it may be noted that in 1934, when only the clipping method was used, a seed set of 26.0% was obtained, while in 1937 with the hot water method 48.3% of the florets set seed. Thus the hot water method would appear to be nearly twice as successful as the clipping method.

Hot and cold water treatments, the latter at about  $2^{\circ}$  to  $4^{\circ}$  C, were compared in 1937 by means of paired panicles. Hot water treatments gave a 47.3% set, while the cold water treatments resulted in only 33.1% set.

A distinct advantage of the hot water method is that the seeds obtained usually are fully developed, are protected by the glumes, and consequently germinate as well as ordinary seed. The low germination from the paired glutinous crosses (Table 3) probably was due to injury inflicted in making an iodine test of the endosperm to detect non-crosses. The percentage of  $F_1$  plants obtained on the basis of florets pollinated as shown in Table 3 is usually distinctly higher for the hot water method. On the basis of supposedly crossed seeds for glutinous varieties the number of  $F_1$  plants that matured ranges from 38.5 to 92.9% from the hot water method and from 26.4 to 54.9% from the clipping method. The number of  $F_1$  plants matured from supposedly crossed seed obtained in 1934 to 1936, inclusive, by the clipping and hot water methods were 47.5 and 73.4%, and on the basis of florets pollinated 12.5 and 26.2%, respectively.



FIG. 2.—Seed set on rice panicles pollinated after emasculation by clipping and hot water methods. Florets on lower portion of panicle were not pollinated.

The crossed seed were germinated in the laboratory on saturated absorbent cotton.<sup>4</sup> The seed were usually treated with Ceresan immediately before placing them on the cotton. No nutrient solution was used. When the seedlings reached a height of 4 to 6 inches, they were transplanted in the field. The germination of seed obtained in 1936

<sup>4</sup>This procedure was suggested by J. Mitchell Jenkins, Associate Agronomist and Superintendent of the Rice Experiment Station, Crowley, La.

was higher than is indicated in Table 3 for a number of seedlings were lost largely because they were growing more slowly than the majority and were transplanted before they attained sufficient size.

An occasional self occurred among the supposedly crossed seed. These may have been due to incomplete removal of anthers, to failure of the temperature used to destroy pollen completely, to wind pollination before the bag was placed over the panicle, or to overlooking unopened florets following treatment. Non-crosses were easily detected, however, and were too few to be of importance. Non-crosses would be most easily overlooked, however, among backcrossed  $F_1$  plants.

An illustration is included in Table 3 of the necessity of using mature anthers in pollination. In 1935 a backcross was attempted with the female parent plants growing in the field while the anthers were collected from  $F_1$  plants growing in a large screened insect cage. Blooming of the  $F_1$  plants was delayed about an hour due to a lower temperature in the shade of the cage, and pollen was probably not fully developed when used. The result was a seed set of only 5.0%, whereas in 1936, when  $F_1$  plants were grown in the field and anthers matured early, a seed set of 41.5% was obtained.

In 1937 the use of glassine bags to protect panicles pollinated following hot water emasculation was practically discontinued. While bags afford protection from wind pollination and insects, they cause breakage of culms in the wind. Difficulty also arises from the panicles growing further out of the boot after pollination and crowding against the end of the bag. Since pollinations were made before normal blooming and the plants used were usually at least several feet from other varieties in flower, the danger of wind or insect pollination was not considered serious.

#### SUMMARY AND CONCLUSIONS

Three methods of emasculating rice florets were used successfully in the field and comparative results are given.

The clipping method necessitates the excision of a portion of the lemma and the removal of anthers by means of tweezers. In experiments in which glumes were clipped but anthers not removed, a reduction in seed set occurred. This was not entirely due to injury from clipping since exposure of the stigma and the immature anthers to the air probably interfered with normal pollination. The seed set was much less when the panicles were unprotected than when covered with glassine bags. When bagged there was no difference in the effect of clipping the lemma, palea, or both glumes. A greater reduction in seed set resulted from clipping in Early Prolific than in Fortuna. Covering uninjured panicles with glassine bags usually lowered the seed set, probably by interference with normal blooming.

The effect of temperatures from 0° to 50° C on emasculation was tested. The treatment was applied by immersing panicles in water contained in thermos bottles. Variations of a few degrees above or below the air temperature hastened opening of florets. When applied in the morning prior to normal blooming, 10-minute treatments at

40° to 44° C destroyed the viability of pollen without injury to other floral organs. Treatments at 0° to about 6° C gave similar but probably less effective results. Florets opened less promptly at low than high temperature. Between 9° and 39° C pollen was unaffected. All tissues were injured at temperatures above 44° C. Treatments at about 43° C had no effect after florets opened and pollen had settled on the stigma.

Pollinations following emasculation by the hot water method gave the highest percentage of seed set. Germination of crossed seed obtained by this method was better because well developed seed, fully protected by the glumes, were obtained. Possibly fewer non-crosses occurred following the use of the hot water method than by the clipping method.

Advantages from the use of the hot water method include: (a) Elimination of injury to the glumes because the florets open in a normal manner; (b) pollinations are limited to mature florets since those that are immature do not open; (c) the tedium of removing anthers is eliminated; (d) the florets open and close prior to normal blooming in surrounding plants, making bagging unnecessary as a protection against wind pollination; (e) varieties having small florets that might be seriously injured by clipping can be pollinated readily; (f) normal seed which germinate well are obtained; and (g) expensive equipment, shelters, and the handling of potted plants are not required.

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## REGISTRATION OF IMPROVED SORGHUM VARIETIES. I<sup>1</sup>

JOHN H. PARKER<sup>2</sup>

IN 1936, 73 varieties of sorghum were registered as standard varieties. Three improved varieties of sorghum were approved for registration in 1937, as follows:

Variety	Reg. No.
Club	74
Finney milo	75
Early Kalo	76

### CLUB, REG. NO. 74

*Description.*—Plants midseason, midtall; stems midstout, mid-juicy, not sweet; tillers abundantly; branches sparsely; midleafy (10 to 12); midribs cloudy; leaf sheaths overlapping moderately; panicles erect, compact, ovoid to ellipsoid; rachis nearly continuous; rachis branches short to mid-long, appressed; glumes pubescent but pubescence partly deciduous at maturity, black, indurate, elliptic, apices obtuse; lemmas appear awnless but have short tip awns which usually do not extend beyond the glumes; stigmas creamy white; kernels much exposed in angles and extending well beyond apices of glumes, large, white with reddish-brown spots, nearly globose, endosperm starchy, corneous layer thin, nucellar layer absent; pedicellate spikelets large, straw-colored, and partly deciduous at maturity; coleoptiles green.

Club is from a head selection made by A. F. Swanson in a head row of Dawn kafir grown at the Hays, Kansas, Branch Experiment Station in 1926. Valuable characteristics of Club are its ability to produce high yields in regions where the season is long enough to permit maturity and under favorable moisture conditions, its immunity to the *Pythium* disease of milo, its relatively high resistance to chinch bug injury, and relatively low infection by kernel smut.

Average yields of club and other varieties tested at Hays, Kansas, during the 8 year period 1929-1936 are as follows:

Variety	Yield, bu. per acre
Kalo.....	32.7
Club.....	29.1
Peterita.....	28.1
Modoc.....	26.5
Western Blackhull kafir.....	26.2
Dwarf Yellow milo.....	24.7
Pink kafir.....	22.4
Dawn kafir.....	21.4

<sup>1</sup>Registered under the cooperative agreement between the Bureau of Plant Industry, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication December 24, 1937.

<sup>2</sup>Agronomist, Kansas Agricultural Experiment Station, and Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Member of the 1936 Committee on Varietal Standardization and Registration of the Society charged with the registration of sorghum varieties.

*Publications.*—SWANSON, A. F., and LAUDE, H. H. Varieties of sorghum in Kansas. Kans. Agr. Exp. Sta. Bul. 266. 1934.

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#### FINNEY MILO, REG. NO. 75

*Description.*—Finney milo is very similar to Dwarf Yellow milo except in being resistant to Pythium root rot, about two days later in maturity and in having more erect upper leaves.

A selection from Dwarf Yellow milo made in 1930 by F. A. Wagner, Superintendent of the Garden City, Kansas, Branch Experiment Station. This selection, named in February, 1937, after Finney County, Kansas, has been grown in nursery rows, field plats, and seed fields at Garden City, Tucumcari, New Mexico, Dalhart, and Chillicothe, Texas, and at other stations, in direct comparison with the parent variety, Dwarf Yellow milo. In all these tests on diseased soil, Finney shows a striking contrast and marked advantage over its parent, often yielding 62 to 75 bushels per acre under irrigation compared to very low yields or failure of the susceptible parent. In 15 cooperative wheat variety tests on Kansas farms during the four years of 1934-1937, Finney milo produced an average yield of 20.0 bushels per acre as compared with 21.3 bushels for Dwarf Yellow milo.

*Publication.*—WAGNER, F. A. Reaction of sorghums to the root, crown, and shoot-rot of milo. Jour. Amer. Soc. Agron., 28:643-654. 1936.

#### EARLY KALO, REG. NO. 76

*Description.*—Plants very early; short (average about 40 inches); stems slender, mid-juicy to dry, not sweet; tillers mid-freely; branches sparsely; leaves few (7-9); midribs cloudy; leaf sheaths overlapping slightly; panicles erect, mid-compact to effuse, ellipsoid to cylindric; rachis about 80% of head length; rachis branches mid-long; glumes pubescent but pubescence partly deciduous at maturity, black to reddish-brown, slightly chartaceous, elliptic, apices obtuse; lemmas usually awned; stigmas yellow; kernels much exposed and extending beyond apices of glumes, mid-size, salmon-yellow with black or dark-red spots, obovoid, endosperm starchy, corneous layer mid-thick to thick, nucellar layer absent; pedicellate spikelets small, reddish-brown, and deciduous at maturity; coleoptiles red.

A selection from Kalo made by A. F. Swanson at the Hays, Kansas, Branch Experiment Station in 1931, from Kalo, which is a selection made at Hays in 1921 from a natural cross between Pink kafir and Dwarf Yellow milo. Early Kalo is about 10 days earlier in maturity than Kalo and the plants are shorter. Because of its earliness, Early Kalo is suited to regions of shorter growing season than Kalo, such as northwestern Kansas and the vicinity of North Platte, Nebr. Early Kalo has been increased for distribution to farmers by the North Platte Experimental Station and is being certified by the Nebraska Crop Growers Association.

Average yields of Early Kalo and other sorghum varieties at Hays for the four-year period, 1933-1936, are as follows:

Variety	Yield, bu. per acre
Peterita.....	12.8
<b>Early Kalo</b> .....	<b>11.2</b>
Kalo.....	10.3
Modoc.....	7.4
Weskan.....	6.9
Day milo.....	6.8
Club.....	5.5
Dwarf Yellow milo.....	5.2
Pink Kafir.....	5.1
Wheatland milo.....	4.6
Western Blackhull kafir.....	4.3
Dawn kafir.....	3.2

*Publication.*—ZOOK, L. L. Grain and forage sorghum varieties at the North Platte Experimental Substation. North Platte, Nebr., Exp. Substa. Bul. 38: 5. 1936.

# A SIMPLIFIED METHOD FOR TESTING THE LODGING RESISTANCE OF VARIETIES AND STRAINS OF WHEAT<sup>1</sup>

I. M. ATKINS<sup>2</sup>

A NEW method for testing the strength of straw, or lodging resistance, of wheat varieties and strains has been used successfully at Texas Substation No. 6, Denton, Texas, in the past two seasons. A preliminary description of this method has been given in a previous paper.<sup>3</sup> Further simplification has been accomplished during the past season and a description of the method is herewith presented. Additional data relating to its accuracy and practicability are also given.

## METHODS AND APPARATUS

The methods and apparatus herein described were developed after a detailed study by the author<sup>4</sup> of morphologic characters associated with lodging in 129 varieties of winter wheat in the 1933 and 1934 seasons. The morphologic character found to be most closely associated with strength of straw, as measured by the Salmon breaking strength machine,<sup>5</sup> was the weight of a section of the culm taken near the base of the plant. These sections are termed "weight per unit length" in this and the previous paper. In the earlier tests these samples were obtained by cutting, with ordinary scissors, sections 10 cm in length from the culm. They were cut about two or three inches above the crown of the plant or near the first straight internode and included one node and parts of two internodes. Strength of straw tests were made with the same sections. The weight of these sections was found to correlate almost perfectly ( $r = 0.968$  for a 3-year average) with breaking strength.

During the past season an instrument for accurately and rapidly cutting these sections was made. This cutter, size and dimensions of which are shown in Fig. 1, was made by a local blacksmith from two sections of  $\frac{1}{4}$ -inch steel plate. The sections of steel are shaped to fit over one another and, after sharpening, operate much the same as a double paper cutter. The space between the jaws is such that 10 cm sections of the culm are cut.

Samples are obtained by cutting the culms at the surface of the ground with a hand sickle and usually are placed in a shed to dry

<sup>1</sup>The studies herein reported were conducted cooperatively by the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Texas Agricultural Experiment Station. Received for publication January 22, 1938.

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<sup>3</sup>ATKINS, I. M. Relation of certain plant characters to strength of straw and lodging in winter wheat. *Jour. Agr. Res.*, 55:99-120. 1937.

<sup>4</sup>*Loc. cit.*

<sup>5</sup>SALMON, S. C. An instrument for determining the breaking strength of straw. *Jour. Agr. Res.*, 43:78-82. 1931.



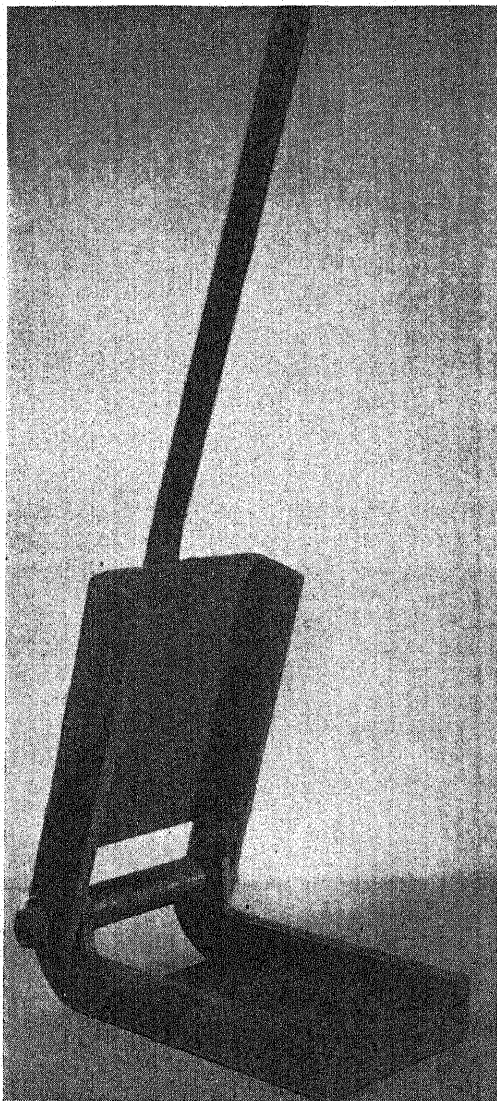


FIG. 1.—Straw cutter used in securing samples for weight per unit length of culm.

before cutting the sections. The upper part of the plant and heads may be discarded or saved for seed as desired. Adjustment of the culms before cutting so that all sections will be comparable with respect to number of nodes has been found unnecessary. Usually each section will include one node only. The leaf sheath is not stripped from the culm although dead loose leaves are discarded. From 100 to 300 sections are cut from each plat. Weighings are made in groups of 100 sections. If large plats of grain are to be tested, additional samples should be taken or, if available, samples should be taken from several replications to give greater accuracy. Fig. 2 shows the cutter in operation. Bundles of 100 culm sections from strong, moderately strong, and weak-strawed varieties of wheat ready for weighing are shown in Fig. 3.

#### EXPERIMENTAL DATA

Data showing the interrelations between weight per unit length of culm, breaking strength of straw, and lodging for winter wheat grown at Denton, Texas, are presented in Table 1. Correlation coefficients between breaking strength of straw and weight per unit length were calculated for all 118 varieties grown for this study, but coefficients between lodging and weight per unit length and between lodging and breaking strength of straw were cal-

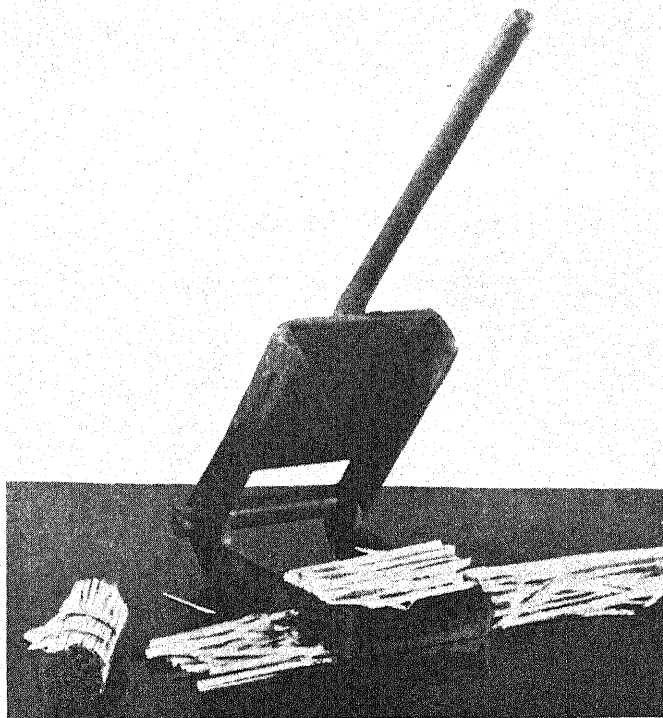


FIG. 2.—Straw cutter in operation with a sample of 100 culms at the left, ready for weighing.

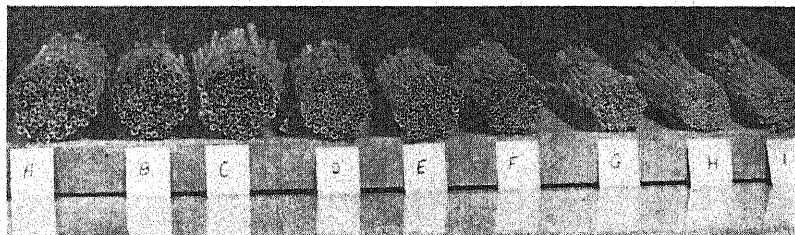


FIG. 3.—Wide variation in size and weight of 100-culm sections cut from strong, moderately strong, and weak-strawed varieties of wheat. A, Sol, 15.7 grams; B, Nittany, 14.8 grams; C, Prosperity, 14.6 grams; D, Red Chief, 14.0 grams; E, Clarkan, 12.8 grams; F, Denton, 10.4 grams; G, Sherman, 7.9 grams; H, Turkey, 7.6 grams; I, Kanred, 7.4 grams.

culated for those varieties only which lodged, that is, for 68 varieties. Two samples of 100 culms each were weighed from each variety in 1936. The correlation coefficient between samples was 0.868.

TABLE 1.—*Interrelations between weight per unit length of culm, breaking strength of straw, and lodging, at Denton, Texas.*

Characters compared		Number of varieties	Correlation coefficient
Breaking Strength	Breaking Strength		
1933	1934	30	0.533
1933	1936	30	0.581
1934	1936	118	0.631
Weight per Unit Length	Breaking Strength		
1934	1934	118	0.918
1936	1936	118	0.948
Av. 1933-36	Av. 1933-36	30	0.968
Av. 1934-36	Av. 1934-36	118	0.945
Weight per Unit Length	Weight per Unit Length		
1933	1934	30	0.690
1933	1936	30	0.611
1934	1936	118	0.721
Lodging in the Field	Breaking Strength		
Av. 1932-36	Av. 1933-36	30	-0.586
Av. 1932-36	1933	30	-0.510
Av. 1932-36	1934	30	-0.443
Av. 1932-36	1936	30	-0.530
1936	Av. 1934-36	68	-0.418
1936	1934	68	-0.405
1936	1936	68	-0.356
Lodging in the Field	Weight per Unit Length		
Av. 1932-36	Av. 1933-36	30	-0.619
Av. 1932-36	1933	30	-0.520
Av. 1932-36	1934	30	-0.552
Av. 1932-36	1936	30	-0.570
1936	Av. 1934-36	68	-0.428
1936	1934	68	-0.380
1936	1936	68	-0.393

Least significant value of  $r$  for 30 varieties = 0.449; 68 varieties = 0.302; 118 varieties = 0.254.

It will be observed that the weight per unit length is closely correlated with strength of straw, and also that the interannual coefficients for weight per unit length are high. This determination also is significantly correlated with lodging. With one exception, these later coefficients are higher than are similar coefficients for breaking strength of straw and lodging. Usually, more than a single year's data on lodging and breaking strength of straw or weight per unit length are necessary to demonstrate significant relations. It is of interest to note, therefore, that in 1936 the coefficients for lodging and breaking strength and for weight per unit length and lodging are both significant. This appears to have been due to the fact that the lodging which occurred in 1936 was not influenced by strong winds or other disturbing factors and more nearly reflected the true strength of straw than can usually be expected.

In 1937, samples were secured from all plats of the replicated breeding nursery at Denton. A total of 94 varieties were grown in this nursery, which was arranged in a modified Latin square with four replications of each variety. Varieties were randomized within each replication with the usual restrictions for modified Latin squares. The correlation coefficients between series in this nursery were all between 0.7 and 0.8. No lodging occurred in 1937 and hence no coefficients for lodging and weight per unit length were calculated.

In addition to being accurate and simple, the determination of weight per unit length of culm requires much less time than determining the breaking strength of straw. In 1936, samples were cut and weighed from 70 varieties in one 8-hour day. It would have taken two men at least two weeks to have made determinations of strength of straw for the same material.

## AGRICULTURAL METEOROLOGY AND CROP FORECASTING IN WESTERN CANADA<sup>1</sup>

J. W. HOPKINS<sup>2</sup>

INVESTIGATIONS in agricultural meteorology may be conveniently classified under three broad headings, depending upon whether their objective is (a) descriptive or comparative meteorology, (b) correlation of meteorological factors with crop growth and development, or (c) crop forecasting with respect to both quantity and quality.

In studies of type (a), detailed information is sought respecting not only the average values over a period of years of the weather elements characteristic of given districts, but also the manner in which these may be expected to vary from season to season. In addition to its purely descriptive value, such information may suggest sources of crop variation previously overlooked.

Categories (b) and (c) have been separated because in (c) one is free to aim at the formulation of a regression equation which will reliably predict the final outturn of crop from antecedent observations, regardless of whether the terms included in the equation have any explicit biological significance or not. In b, on the other hand, one is interested not only in the end result, but also in tracing through the influence of successive causal factors on the actual developmental sequence; information which may be important in the appraisal of cultural methods or in the formulation of plant breeding programs.

Actually, of course, these three aspects of the subject are mutually inter-connected, and, under Canadian conditions at least, it would seem to be impossible to prosecute (c) successfully if (a) and (b) are neglected. The reasons for adopting this view are illustrated by the following comments respecting the problem of forecasting the western Canadian wheat crop.

This crop, as is well known, is subject to great annual vicissitudes. Since weather conditions are generally agreed to be a major factor in the fluctuation of acre yields from year to year, and since these operate on the crop from the beginning of its growth, it has naturally been suggested that if the relation between weather conditions during successive periods of the growing season and the subsequent crop yields could be determined, justifiable approximate estimates of the probable forthcoming production might be made at an earlier date than is now feasible, and could be periodically improved upon as the season advanced and further weather data became available.

This, of course, presupposes that adequate series of reliable yield data are available for correlation with the meteorological observations. In Canada, at any rate, this is far from being the case, and an important advance might be made if a set of permanent agrometeorological

<sup>1</sup>Contribution from Division of Biology and Agriculture, National Research Laboratories, Ottawa, Canada. Also presented at the annual meeting of the Society held in Chicago, Ill., December 1 to 3, 1937. Received for publication December 27, 1937.

<sup>2</sup>Statistician.

plots were established and maintained at each of the Dominion Experimental Farms and Stations within the wheat zone, in order to accumulate over a period of years comparable data with respect to the standard varieties.

Moisture supply is probably the most important single factor influencing yield. The moisture available to the western Canadian spring wheat crop consists of the amount present in the soil at the time of sowing, supplemented by the quantities accruing from rainfall during the growing season. Under prairie conditions both combined are seldom equal to the absorptive capacity of the crop. This is illustrated by the results of soil moisture experiments made at Swift Current, Saskatchewan, by Barnes and Hopkins (2).<sup>3</sup> Crops were grown in tanks, 15 inches in diameter and 5 feet deep, filled with soil and placed in pits in the centre of field plots growing the same crops as those in the tanks. Periodic weighing of the tanks by means of a travelling gantry permitted changes in soil moisture to be followed. By this procedure, it was found that in 1928, for example, only during a period of about two weeks out of the whole growing season was moisture received from rainfall in amounts sufficient to offset the quantities used up in transpiration and evaporation.

Of course, the initial soil moisture, and the subsequent balance of loss and gain, vary from year to year owing to differences in the precipitation prior to and during the growing season. Since the results of these tank experiments over a period of years (1) indicate a rather close relation between available soil moisture and yield, it might be thought that there would consequently be a close correlation between yield and precipitation. Statistical studies by the author (6, 7), however, yielded multiple correlation coefficients of only 0.7-0.8 between yield per acre in various crop districts of Alberta and Saskatchewan and precipitation during the growing season and the preceding autumn. While these are quite significant statistically, unfortunately the degree of association indicated is not high enough to be of practical utility in crop forecasting. The annual acreage sown to wheat in Canada is of the order of 25,000,000, and the average production for the 11-year period 1926-36 approximately 367,000,000 bushels. Hence, in order to reduce the standard error of estimate to 20,000,000 bushels, which is roughly  $5\frac{1}{2}\%$  of the mean, the residual standard deviation from the regression equation must be less than 1 bushel per acre.

The fact that a higher correlation of yield with precipitation was not obtained may be due, of course, to the effect of other factors on the crop, and also, as was pointed out in the original paper, to imperfections in the data themselves. However, a study of the incidence of precipitation in the area concerned (10), suggests that part of the discrepancy may be due to the fact that not all of the rainfall recorded by rain gauges contributes in an equal manner to the supply of soil moisture.

The heights of the columns in Fig. 1 show graphically the frequency of occurrence of different daily totals of precipitation (exclusive of

<sup>3</sup>Figures in parenthesis refer to "Literature Cited," p. 321.

zero) over a 17-year period at four representative points in the wheat area during each of the five months of the growing season. The daily totals are grouped in ascending classes of  $1/10$  inch, and in all cases the smaller daily amounts are seen to be much the more numerous.

Fig. 2 shows the actual quantities of rain accruing from the different classes of daily amounts. As before, the grouping is by ascending intervals of  $1/10$  inch, but in this case the total height of the columns

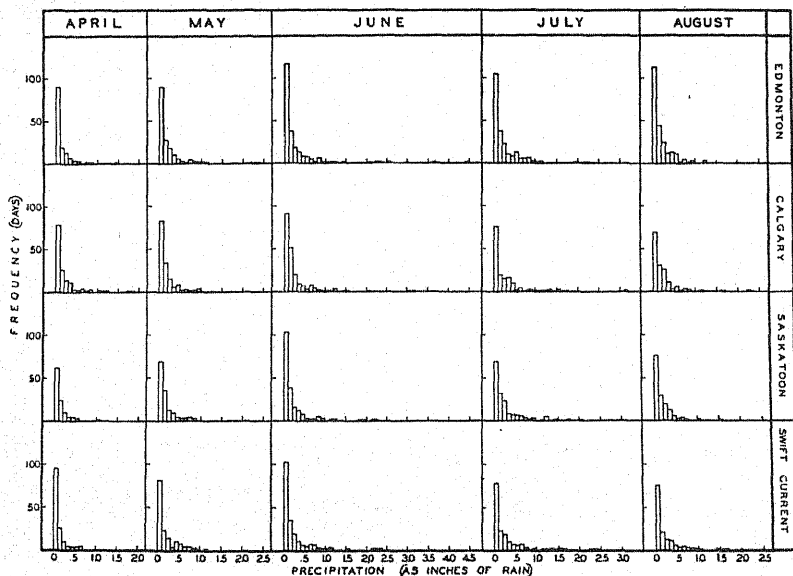


FIG. 1.—Frequency distribution of daily totals of precipitation (excluding zero) at meteorological stations in central and southern Alberta and Saskatchewan during five spring and summer months, 1916-1932.

is proportional not to the frequency of occurrence, but to the total inches of rain contributed over the 17-year period. The larger daily amounts, whose infrequency caused them to figure so inconspicuously in the preceding diagram, are now seen to provide an appreciable proportion of the total, particularly in June and July.

The solid black columns in Fig. 2 represent the total rain received in the various categories of daily amounts during the eight-driest Aprils, Mays, etc., of the 17-year period (1916-1932). The concentration of these in the left-hand portion of each cell of the diagram indicates that, during the drier months, a major part of such precipitation as did occur consisted of relatively light showers. There is thus a qualitative as well as a quantitative difference between the months of above and below average precipitation.

This is a factor which must be taken into account in attempts to correlate crop yields with precipitation, for under prairie conditions not all of the moisture received at any time as rain penetrates into

the soil and becomes available to plants. A certain amount is retained by the surface layer and subsequently evaporated directly into the atmosphere. The amounts thus lost, which will depend on soil type, vegetational cover, and the meteorological conditions subsequent to precipitation will determine a lower limit of effective rainfall. In consequence, the efficiency of conservation by the soil of different amounts of rain will not be the same, and three separate falls of 0.25

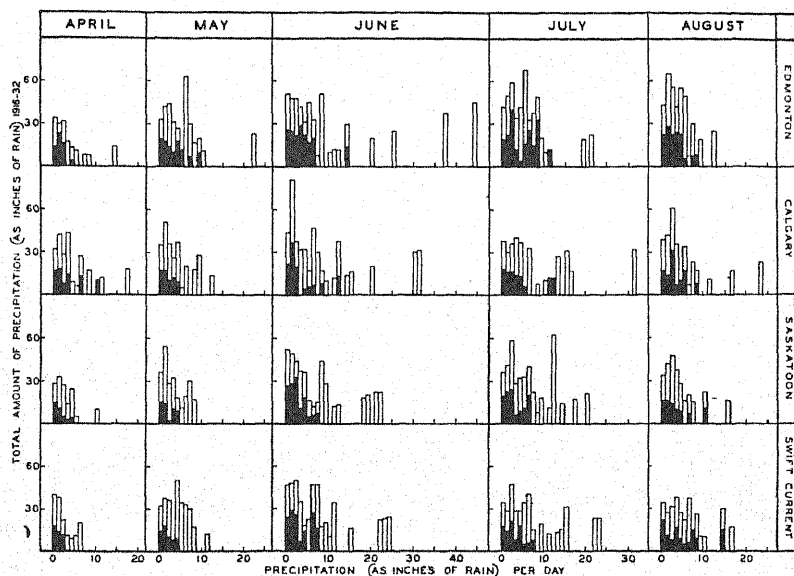


FIG. 2—Proportion of total precipitation at meteorological stations in central and southern Alberta and Saskatchewan during five spring and summer months, 1916–1932, received in daily amounts of specified sizes. A, during entire period (total height of column) ; B, during the eight driest Aprils, Mays, etc., at each station (lower blackened portion).

inch, for example, cannot be assumed to be equivalent in effect to one fall of 0.75 inch.

The actual penetration into the soil of individual rainfalls has not, as far as the writer knows, been studied in any great detail in Canada. A study of this sort would certainly seem to be desirable in view of the fact that the data shown in Fig. 2 indicate that in the 8 driest Aprils out of the 17 considered, from 54% to 100% of the total rain at the four stations was in daily amounts of  $3/10$  inch or less, and that even in June small falls of this nature constituted on the 8-year average from 45% to 68% of the total.

When the records for individual years are examined, even more striking contrasts are revealed. Thus, a study of the June rainfall at Calgary and Saskatoon in each of the 17 years 1916–1932 (10) shows that in the moister months, the proportion of the total occurring in daily amounts of  $3/10$  inch or less was in the neighborhood of 20%.



In months of smaller total precipitation it was on the average higher, but fluctuated considerably, in some instances attaining 100%, in others being only of the order of 40%, and in one year at Saskatoon only 10% of a June rainfall totalling but 2.04 inches occurred in amounts of  $\frac{3}{10}$  inch per day or less. Even in periods of below-average moisture, therefore, similar amounts of total precipitation may be of quite different effectiveness in different seasons.

As is well known, the amount of precipitation during an individual rainstorm sometimes shows considerable local variation. This is a subject which has recently been investigated on a comprehensive scale in Oklahoma by the Division of Climatic and Physiographic Research of the Soil Conservation Service (17), with very illuminating results. Comparable detailed observations are not available in Canada, but some information has been obtained from the 10-year records of daily precipitation during the spring and summer months at a series of meteorological stations in each of four districts representative of central and southern Alberta and Saskatchewan. Over the 10-year period 1923-1932, local variation in the total rainfall received at different stations in the same district during the same month was found to result in a standard deviation of no less than 40% to 50% of the mean; while if, instead of the total of all rain received during the month, attention is confined to the quantity received in amounts exceeding  $\frac{3}{10}$  inch per day, the local variations in this give rise to a standard deviation of from 50% to 70% of the mean, indicative, of course, of an asymmetrical frequency distribution. Thus, the same total amount of rainfall may be the outcome of appreciably different intensities of precipitation, not only from year to year at the same point, but from point to point during the same year. This increases the desirability of rainfall penetration studies, for not much success is likely to be attained in attempting to correlate crop yields with soil moisture which is nonexistent.

Temperature conditions in western Canada are more stable from year to year than are the amounts of precipitation (6). Annual variations are most pronounced in the spring, and indications have been obtained from statistical studies (6) that above-average temperatures at this time have a favorable effect upon wheat yield, whereas in midsummer their effect appears to be depressive. On the whole, though, it would seem that the effect of temperature on yield is secondary to that of rainfall. Furthermore, during the summer months at least, annual variations in temperature are to some extent correlated with those of precipitation (11), above-average rains being associated with below-average temperatures.

It has been shown (8, 9), however, that temperature conditions during the period of formation and ripening of the wheat grain may affect an important quality factor, namely, protein content. Above-average temperature during this period of crop development has been found to be associated with an increased percentage of nitrogen in the mature grain. This is presumably the result of an actual reduction in carbohydrates due to accelerated respiration, the few quantitative studies that have been made with wheat indicating that the rate of

respiration is in fact approximately doubled by each  $10^{\circ}\text{C}$  rise in temperature.

When one seeks to correlate crop growth or yield with temperature observations, two questions respecting such observations arise.

The first of these is whether the so-called "mean daily temperature" calculated by averaging the daily maximum and minimum is in fact a reliable estimate of the true daily mean. Average diurnal temperature curves (11) for the spring and summer months obtained from hourly observations at Swift Current, Saskatchewan, are all to some extent asymmetrical, the number of hours from minimum to maximum being less than that from maximum to minimum, particularly, of course, in spring when the days are shorter. One might expect, therefore, that the mean of maximum and minimum would tend to over-

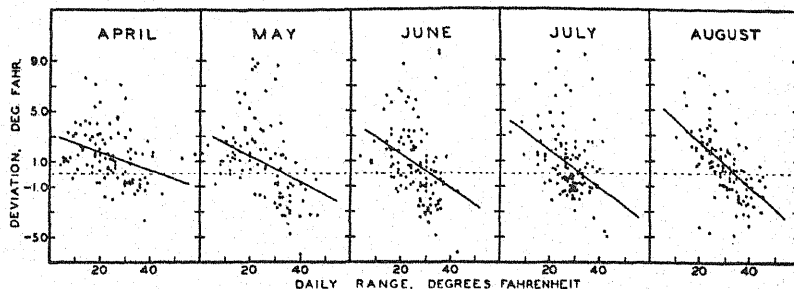


FIG. 3.—Relation between deviation of two-point from 24-point daily mean, and daily range in temperature at Swift Currents, Saskatchewan. Computed from four years' data (1922, 1923, 1925, and 1927).

estimate the true daily mean, and this does in fact seem to be the case, as for all five months studied it gives values which are on the average higher than those obtained from the 24 hourly observations. The average discrepancy, which seems to be a function of the season, ranges from  $+1.74^{\circ}\text{F}$  in April to  $+0.74^{\circ}\text{F}$  in July. It is thus of moderate dimensions. However, the discrepancies actually occurring on individual days at this station vary considerably, as is shown by the vertical scatter of points in Fig. 3. The maximum difference in the 4-year period to which these data refer is  $+9.7^{\circ}\text{F}$ , which occurred during the month of June.

The source of such deviations, of course, is to be found in the various departures of the actual daily temperature sequences from the average diurnal trend, and it may be noted that there is some correlation between the daily range in temperature and the difference in the two averages. Such discrepancies will, of course, be of most importance in connection with processes such as respiration, which vary in a non-linear fashion with temperature.

The second question is whether the readings of thermometers placed in the usual standard screens provide an adequate indication of the temperature conditions actually experienced by the crop. Micrometeorological studies in both Europe and India (4, 15, 16) indicate that this may not always be so. However, a suitable series of observations

under the environmental conditions actually prevailing in western Canada would seem to be required in order to settle this point.

The effect of wind upon crops is a subject about which little is known. Reference is intended, of course, not to mechanical damage, but to effects arising from alterations in the transpiration rate. Martin and Clements (13) exposed sunflower plants in the greenhouse to artificial winds of different velocities and obtained striking results, not only upon transpiration, but also upon growth in general as measured by the production of dry matter. In so far as crop growth is concerned, the importance of wind as a factor will depend first of all upon the extent to which it varies from year to year, and secondly, upon whether the effects of such variations on plants growing in the mass in the field are as pronounced as those observed in plants growing individually in the greenhouse.

So far attention has been confined to meteorological elements which, although they may vary in amount or intensity, are present in all seasons. There are also, of course, factors of the catastrophic class, such as frost and hail, which, although of relatively infrequent occurrence, may nevertheless on occasion produce appreciable effects. It is therefore necessary to have some quantitative method of estimating the reduction in yield resulting from such events. In this connection a promising line of approach has been developed by American workers in investigating the effects of mechanical injury in simulation of hail damage, and determining the effect on yield of corn (3) and flax (12) of differences in the degree of injury and time of infliction.

Plant diseases may also be considered to fall in this category. The degree to which these establish themselves and develop is generally believed to be dependent on environmental factors. From the work already done by several investigators, however, it is apparent that the relation between weather conditions and pathogen development is by no means simple, and it will probably be found most practical to compute the effect on yield from visual or other estimates of the actual degree of infestation at specified stages of crop development.

Thus, Greaney (5) has found from field experiments extending over 8 years a linear relation between the extent of infection by black stem rust and the reduction in yield of Marquis wheat, each additional 10% infection resulting on the average in a loss of 5.4% of the possible crop. By appropriate methods, similar relations could no doubt be worked out for other plant diseases. It may be necessary to do this for individual varieties. Rust-resistant hybrids, for example, have now been produced and in the course of a few years will be extensively grown in sections of Manitoba and Saskatchewan. The introduction of notably drouth-resistant varieties would, of course, require meteorological correlations in general to be worked out on a varietal basis.

Some mention should also be made of the factor of weed competition. As a result of the extensive type of farming practiced, weed infestation has attained serious proportions in many areas of western Canada. Barnes (1) is of the opinion that under conditions of limited rainfall, competition for the available soil moisture by weeds consti-

tutes a greater hazard to crop growth than either plant diseases or insect pests, and presents experimental data showing striking reductions in wheat yield at Swift Current, amounting in one year to over 75%, as a result of competition from Russian thistle.

Pavlychenko and Harrington (14) have pointed out that normally the development of cereal plants with respect to both tops and roots is at the outset much more rapid than that of any of the dicotyledonous weeds they studied, except wild mustard. Under favorable conditions, therefore, this capacity for rapid initial development should enable cereals to take more or less complete possession of the available soil area before the weeds attain sufficient growth to compete seriously with them. By 21 days after emergence, however, it was found that most noxious weeds had both greater root systems and larger assimilation surfaces than had any of the cereals studied, with the result that no cereal crop can compete successfully with them after this stage of development. Consequently, any circumstance which retards the early development of the cereals also reduces their subsequent competitive efficiency.

There is thus the possibility of an important indirect influence of early weather conditions on yield, due to a shift in the competitive balance. Here again, however, it will probably be found most practical to devise some simple means of specifying the intensity of weed infestation from observations on the growing crop, and to determine the effect of variations in infestation from year to year on the yield of infested in comparison with weed-free stands. Data bearing on this latter question are gradually being accumulated by the Associate Committee on Weed Control of the National Research Council of Canada.

It may be judged from the foregoing remarks that, in the view of the writer at least, the determination of the regression equations necessary to predict Canadian wheat production from meteorological observations with the degree of accuracy required in practice will be a lengthy and tedious process, requiring the accumulation and analysis of large numbers of appropriate observations. It may well be that as far as the routine procedure of crop forecasting is concerned, the most effective method is that of observations on the growing crop along the lines of the English scheme (18), supplemented perhaps by later meteorological and ancillary data. The elucidation of the actual mode of action and interaction of the various weather elements on growth and yield remains, however, a subject of sufficient interest and importance in itself to justify continued attention.

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## GERMINATION TESTS WITH SUGAR BEET SEED<sup>1</sup>

A. W. SKUDERNA AND C. W. DOXTATOR<sup>2</sup>

CONSIDERABLE difference in methods used for conduct of germination tests with sugar beet seed exists among laboratories interested in this work. It has been the custom of the German seed trade<sup>3</sup> to prescribe the use of fine-grained quartz sand, moistened to 60% of its moisture-holding capacity, as a "germination bed" for sugar beet seed. The containers used are of porcelain ware such as soup plates or bread tins. A representative sugar beet seed sample is weighed to ascertain number of seed balls per gram and kilogram. The sample is then reduced to 100 seed balls. These are lightly pressed into the sand, a piece of window glass is placed over the container, and left in place during the 14-day period of test. An alternating temperature of 30° C for 6 hours and 20° C for 18 hours is maintained during the period of the test. The reading of germinating seed balls and sprouts therefrom is made at the end of 7 days and 14 days, respectively. Results are reported in percentage germination per 100 seed balls, number of sprouts per 100 seed balls, and number of sprouts per kilogram of seed. This method is being used by many of the U. S. Beet Sugar Company laboratories in determining whether the seed purchased comes up to the prescribed Magdeburg standard on which European and domestic beet seed is purchased.

The Association of Official Seed Analysts of North America<sup>4</sup> recommend the soaking of beet seed for 2 hours at a temperature of 20° C before germination; the use of folded blotting paper instead of sand; and the making of a preliminary count of germinating seed balls in 4 days and the final count in 10 days. There is a further recommendation that the germination of beet seed be confined to the determination of the percentage of balls that sprout.

Still another modification of these methods is used by one commercial seed testing laboratory<sup>5</sup> in which the soaked seed is placed for one day into a warm germinating oven maintained at 30° C and then alternated between the warm and cold germinating ovens for the balance of the germination period. Counts are made on the 4th, 7th, 11th, and 14th day of the test. Only sprouts showing normal root and root hair development are considered normal and are counted.

The purpose of this paper is to present results from a series of tests in which the various methods mentioned and others are compared, and to propose a uniform method of procedure in the conduct of sugar beet seed germination tests.

<sup>1</sup>Contribution from the American Beet Seed Company, Rocky Ford, Colorado. Received for publication January 11, 1938.

<sup>2</sup>General Manager and Plant Breeder, respectively. Acknowledgment is due to Miss Elizabeth Seamans, station clerk, for capable assistance in obtaining data used in this paper.

<sup>3</sup>German regulations (norms) governing the trade in sugar beet seed. Magdeburg, Germany, 1914.

<sup>4</sup>Rules for seed testing. U. S. D. A. Cir. 406. 1928.

<sup>5</sup>Correspondence received by senior author.

## MATERIALS AND METHODS

## THE SEED SAMPLE

A representative lot of home-grown seed, 1936 crop, was used throughout the study to insure uniformity of seed for the comparative tests discussed in this paper. The seed lot was thoroughly composited by splitting the sample with a Boerner grain sampler, first to a 20-gram sample and subsequently further reducing it to approximately 100 seed balls. This random selected 100 seed ball sample was compared as to germination with a seed sample specially prepared so as to conform in percentage amounts to the various sizes of seed balls present in the seed lot. The seed ball size and percentage amount was determined by placing the seed for 5 minutes in a mechanical shaker having screens of 4.00-mm; 3.5-mm; 3.0-mm; and 2.5-mm size, weighing the amount of seed remaining on each screen, and using the proportions found in preparation of the 100 seed ball selected sample. For each comparison, four tests of 100 seed balls each were made.

## THE SUBSTRATUM

A paper toweling of an absorbent weight, 11 by 15 inches in size, folded double, was used as a substratum, making a  $5\frac{1}{2}$  inch by  $7\frac{1}{2}$  inch seedbed. In these tests it was found that this grade toweling supplied the needed moisture and allowed sufficient aeration, provided due care was used to prevent excess wetting of the toweling.

Standard germination blotting paper (granite) of 250-m weight was used as a substratum. The sheets were cut 8 by  $9\frac{1}{2}$  inches and folded in half, making a  $4\frac{3}{4}$  by 8 inch seedbed.

Fine-grained river sand screened through a 35-mesh screen was used for the sand substratum. This sand was washed free from alkali salts, sterilized with live steam and placed in porcelain containers  $7\frac{1}{2}$  by  $11\frac{1}{2}$  inch in size, filled about  $\frac{3}{4}$  inch deep. The sand was moistened to 60% of its calculated moisture-holding capacity.

## THE WATER

Tap water and distilled water were compared in these tests. The tap water was derived from artesian sources, having a mixed salt content of approximately 800 p. p. m., the salts being mostly sodium.

For comparison tests the tap water was distilled and both sources of water used separately to soak seed and to moisten paper toweling, blotting paper, or sand as required by the test in question.

## THE GERMINATORS

Two Minnesota seed germinators, thermostatically controlled, were used in the tests. One of the germinators was kept at a temperature of  $20^{\circ}$  C and the other at  $30^{\circ}$  C. The seed trays from one germinator were transferred as required from one germinator to the other, assuring thereby a sharp fluctuation in temperature.

## THE GERMINATION TEST

Particular attention was given to the fulfillment of requirements of each test. For those tests indicating soaking of seed, this was done for 2 hours in water at  $20^{\circ}$  C. In all tests requiring an alternation of temperatures, this was accomplished by germinating the seed for 16 hours at  $20^{\circ}$  C and 8 hours at  $30^{\circ}$  C. Germination counts were made at 4, 7, and 14 days. Results of only 7- and 14-day germinations are given for the "A" series of tests. In making germination counts, only sprouts

showing normal root and root hair development were counted, and a record kept of vigor and condition of seedling. The sprouted seed balls were removed to an empty blotter at the time germination counts were made. The sprouts were counted and removed from the seed balls and final count made on the 14th day.

#### DESCRIPTION OF TESTS

A total of 84 individual tests, each repeated in quadruplicate was made in the "A" series. The detail is as follows:

*Series A.*—1. Comparison of 30° C temperature for first 24 hours and then alternating at 20° C for 16 hours and at 30° C for 8 hours for duration of test (method designated as R) versus standard procedure (S) wherein the temperature was alternated at 20° C for 16 hours and 30° C for 8 hours from beginning of test. Test 1-24, inclusive.

2. Comparison of continuous 20° C versus continuous 30° C temperature for entire period of test. Tests 25-48, inclusive.

3. Seed ball size (4.0 mm; 3.5 mm; and 2.5 mm) versus random size in relation to germination of sugar beet seed. Tests 49-84, 4-6, 10-12, 16-18, and 22-24, inclusive.

4. Comparison of type of substratum, paper toweling, blotter, and sand. Paper toweling, tests 1-4-7, and every third test to 82, inclusive. Blotter, tests 2-5-8, and every third test to 83, inclusive. Sand, tests 3-6-9, and every third test to 84, inclusive.

5. Comparison of presoaking beet seed for 2 hours prior to germination versus dry seed. Tests involving presoaked seed 13-24; 31-36; 43-48; 55-60; 67-72; and 79-84, inclusive. Tests involving dry seed 1-12; 25-30; 37-42; 49-54; 61-66; 73-78, inclusive.

6. Effect of tap water versus distilled water in presoaking seed. Tap water, tests 13-18; 31-33; 43-45; 55-57; 67-69; and 79-81, inclusive. Distilled water, tests 19-24; 34-36; 46-48; 58-60; 70-72; and 82-84, inclusive.

7. Effect of tap water versus distilled water in moistening the substratum. Tap water used in tests 1-6; 13-18; 25-27; 31-33; 37-39; 43-45; 49-51; 55-57; 61-63; 67-69; 73-75; and 79-81, inclusive. Distilled water used in tests 7-12; 19-24; 28-30; 34-36; 40-42; 46-48; 52-54; 58-60; 64-66; 70-72; 76-78; and 82-84, inclusive.

*Series B.*—1. Comparison of 4-, 7-, 10-, and 14-day period of germination to determine minimum period required. Forty sets of samples of sugar beet seed used other than those included in the A series.

2. Comparison of sand, soil, and blotting paper substratum (1935 tests) and 4-, 7-, 10-, and 14-day periods of germination.

3. The effect of presoaking sugar beet seed for 2 hours prior to germination test on germinability of seed of different ages. Seed of 6, 18, and 30 months of age used with sand as substratum.

#### EXPERIMENTAL DATA

Comparison of 30° C temperature for first 24 hours and alternating for balance of the germination test at a temperature of 20° C for 16 hours and 30° C for 8 hours daily (R method), with an alternating temperature of 20° C for 16 hours and 30° C for 8 hours for the entire period of test (S method) gave results shown in Table 1.<sup>6</sup>

<sup>6</sup>The analysis of variance method was used in the reduction of all data in this paper. Fisher, R. A. Statistical Methods for Research Workers. London: Oliver



TABLE 1.—*Comparing the "R" and "S" methods of germinating sugar beet seed (12 tests each), Rocky Ford, Colo., 1937.*

Days	"R" method		"S" method	
	A*	B*	A*	B*
7.....	82.10	176.27	81.85	168.02
14.....	86.50	184.75	85.50	177.54

Required for significance:

7 days, 6.38% germination and 19.90 number of sprouts.

14 days, 3.25% germination and 18.93 number of sprouts.

\*A refers to germination and B to number of sprouts per 100 seed balls.

Comparing the results obtained from maintaining continuous temperature of 20° C versus 30° C for the entire period of the test, the figures given in Table 2 were obtained.

TABLE 2.—*Effect of continuous temperatures of 20° C and 30° C during period of test on germination of sugar beet seed (12 tests each), Rocky Ford, Colo., 1937.*

Days	20° C		30° C	
	A*	B*	A*	B*
7.....	80.58	172.42	80.15	162.88
14.....	87.50	185.08	85.15	172.50

Required for significance:

7 days, 7.09% germination and 25.07 number of sprouts.

14 days, 4.75% germination and 23.52 number of sprouts.

\*See footnote to Table 1.

A combined analysis of the 48 tests involving the four temperature methods, "R" and "S" method, 20° C and 30° C for the 14-day germination percentage and the 14-day sprout counts was made. The analysis of variance is given in Table 3.

The 12 substrata moisture treatments which were used with the temperature methods were presoaking of seed in tap versus distilled water, versus dry seed. Each of the moisture treatments were used with the three substrata *viz.*, toweling, blotter, and sand.

To determine the effect of a selected sample compared to a random sample of beet seed, 12 comparison tests were made on each of the following seed ball sizes: 4.0 mm; 3.5 mm; 2.5 mm; and seed of random size obtained from the mechanically reduced sample of seed by use of a Boerner grain sampler. The results are shown in Table 4.

As indicated in the discussion of the seed sample, a seed sample was specially prepared so as to conform in percentage amounts to the various sizes of seed balls present in the lot of seed tested. The percentage amounts of each seed size in a 25-gram sample, together with the weighted germination of such a sample compared to the

TABLE 3.—*Analysis of variance of four temperature methods tested with 12 substrata and moisture treatments.*

Variation due to	Degrees of freedom	Sum of squares	Mean square	F*	Standard error
14-day Germination, %					
Replication.....	3	14.277	4.7590	—	
Temperature methods....	3	162.707	54.2356	6.47†	
Substrata and moisture treatments.....	11	581.537	52.8670	6.30†	
Temperature methods × substrata and moisture treatments.....	33	761.423	23.0734	2.75†	
Error.....	141	1182.722	8.3881	—	1.45
Total.....	191	2702.666			
14-day Sprout Counts					
Replication.....	3	2031.938	677.3127	3.01†	
Temperature methods....	3	5313.230	1771.0767	7.87‡	
Substrata and moisture treatments.....	11	6248.000	568.0000	2.53†	
Temperature methods × substrata and moisture treatments.....	33	13331.083	403.9722	1.80†	
Error.....	141	31713.562	224.9189	—	7.50
Total.....	191	58637.813			

\*Obtained from Snedecor, G. W. Calculation and Interpretation of Analysis of Variance and Covariance. Ames, Iowa: Collegiate Press, Inc. 1934.

†Exceeds the 5% point of significance.

‡Exceeds the 1% point of significance.

TABLE 4.—*Seed ball size in relation to germination of sugar beet seed, Rocky Ford, Colo., 1937.*

Days	4.0 mm.		3.5 mm.		2.5 mm.		Random size	
	A*	B*	A*	B*	A*	B*	A*	B*
7.....	89.81	217.02	84.98	163.27	69.52	109.54	81.85	168.02
14.....	92.79	224.56	87.79	168.90	74.00	118.86	84.88	177.54

Required for significance:

7 days, 2.58% germination and 7.41 number of sprouts.

14 days, 1.64% germination and 5.25 number of sprouts.

\*See footnote to Table 1.

actual germination of the random selected sample, is as follows:

$$\frac{36.28\% (92.79) + 34.44\% (87.79) + 29.78\% (74.00)}{100} = \frac{85.56\%}{\text{weighted germination.}}$$

The actual germination of the random sample was 84.88%. The required significance on the basis of 12 tests each is 1.15% germination and 3.68 number of sprouts per 100 seed balls.

To evaluate the influence of various substrata on the percentage germination and number of sprouts per 100 seed balls, 28 tests each

with paper toweling, blotting paper, and sand were made. The results are shown in Table 5.

TABLE 5.—*A comparison of paper toweling, blotting paper, and sand as a substratum for sugar beet seed, Rocky Ford, Colo., 1937*

Days	Paper toweling		Blotting paper		Sand	
	A*	B*	A*	B*	A*	B*
7.....	82.59	168.14	83.05	173.23	78.21	159.80
14.....	87.15	179.29	86.63	179.38	83.05	168.99

Required for significance between averages of 28 tests:

7 days, 3.83% germination and 6.78 number of sprouts per 100 seed balls.

14 days, 2.31% germination and 6.33 number of sprouts per 100 seed balls.

\*See footnote to Table 1.

Presoaking of seed for 2 hours prior to commencement of the germination test for the purpose of loosening the seedcap and causing the seed to absorb moisture more rapidly, has been widely practiced. To test the efficiency of this pretreatment, 42 comparison tests were made between presoaked and dry seed on a fresh crop of 1936 seed. The results are shown in Table 6.

TABLE 6.—*The effect of presoaking sugar beet seed for 2 hours prior to germination as compared to dry seed, Rocky Ford, Colo. 1937.*

Days	Presoaked seed		Dry seed	
	A*	B*	A*	B*
7.....	82.21	167.37	80.36	166.75
14.....	85.51	174.73	85.41	177.03

Required for significance between average of 42 tests:

7 days, 3.51% germination and 5.54 number of sprouts per 100 seed balls.

14 days, 1.13% germination and 4.79 number of sprouts per 100 seed balls.

\*See footnote to Table 1.

In presoaking of seed, two different sources of water were used, tap and distilled. The tap water had an alkali salt content of approximately 800 p.p.m. The results from using this quality water compared to distilled water in presoaking seed are shown in Table 7.

TABLE 7.—*Effect of tap water compared with distilled water in presoaking beet seed with relation to germination results, Rocky Ford, Colo. 1937.*

Days	Tap water		Distilled water	
	A*	B*	A*	B*
7.....	81.25	167.29	81.32	166.83
14.....	85.57	176.24	86.65	175.52

Required for significance between average of 42 tests:

7 days, 3.51% germination and 5.54 number of sprouts per 100 seed balls.

14 days, 1.13% germination and 4.79 number of sprouts per 100 seed balls.

\*See footnote to Table 1.

Tap and distilled water comparisons were also made with respect to effect on moistening the substratum, involving 14 tests for each comparison, the results of which are shown in Table 8.

TABLE 8.—*Effect of tap water compared with distilled water in moistening the substratum, Rocky Ford, Colo., 1937.*

Days	Test	Tap water			Distilled water		
		Paper toweling	Blotting paper	Sand	Paper toweling	Blotting paper	Sand
7.....	A*	82.14	83.75	77.86	82.98	82.36	78.57
14.....	A*	87.06	86.68	83.91	88.50	85.38	85.47
7.....	B*	166.57	176.20	159.10	169.71	170.27	160.50
14.....	B*	184.00	182.38	174.15	185.44	175.65	178.19

Required for significance between averages of 14 tests:

7 days, 5.42% germination and 9.52 number of sprouts per 100 seed balls.

14 days, 3.27% germination and 8.95 number of sprouts per 100 seed balls.

\*See footnote to Table 1.

In 1936, a test was conducted with 40 sets of germination samples in quadruplicate in the comparison of 4-, 7-, 10-, and 14-day periods of germinating sugar beet seed. In this test, paper toweling was the substratum and the standard method of alternating temperatures was used throughout the test. The results are shown in Table 9.

TABLE 9.—*Comparison of 4-, 7-, 10-, and 14-day germinating periods on the germination percentage and sprout counts per 100 seed balls, Rocky Ford, Colo., 1936.*

4 Days		7 Days		10 Days		14 Days	
A*	B*	A*	B*	A*	B*	A*	B*
69.37	141.22	83.34	170.44	85.98	180.25	86.44	182.49

\*See footnote to Table 1.

In a comparison test conducted in 1935, 35 germination test plantings each were made in sand, greenhouse soil, and in blotting paper to determine the merits of each. A temperature of 30° C was maintained throughout the test. The seed used was from the 1935 crop. The results are shown in Table 10.

TABLE 10.—*Comparison of sand, soil, and blotting paper as substrata for germinating sugar beet seed for 4-, 7-, 10-, and 14-day periods at 30° C, Rocky Ford, Colo., 1935.*

Substratum	4 days		7 days		10 days		14 days	
	A*	B*	A*	B*	A*	B*	A*	B*
Sand.....	70.5	141.5	76.0	175.0	81.5	181.0	82.5	183.0
Soil.....	67.5	152.0	84.0	180.0	85.0	186.0	85.0	186.0
Blotting paper..	73.0	138.0	81.0	167.0	83.0	170.0	84.0	172.0

\*See footnote to Table 1.

A number of tests were conducted in 1935 on presoaking of seed of different ages, using sand as the substratum and a 30° C temperature throughout the germinating period. Seed was presoaked in tap water for a period of 2 hours prior to germination. The results are shown in Table 11.

TABLE 11.—*The effect of presoaking sugar beet seed for 2 hours prior to germination on percentage germination and number of sprouts per 100 seed balls (sand substratum), Rocky Ford, Colo., 1935.*

Age of seed, months	Treatment	Percentage germination				
		4 days	7 days	10 days	14 days	Total, %
6	Presoaked	73.0	5.0	—	—	78.0
	Dry	67.5	4.5	3.0	—	75.0
Increase for presoaking						3.0
18	Presoaked	81.0	7.0	3.0	—	91.0
	Dry	72.0	9.0	4.0	2.0	87.0
Increase for presoaking						4.0
30	Presoaked	78.0	8.0	4.0	—	90.0
	Dry	63.5	12.5	7.0	3.0	86.0
Increase for presoaking						4.0

### DISCUSSION OF RESULTS

In comparing results obtained from the "R" and "S" methods of germinating sugar beet seed (Table 11), no significant differences were obtained, due largely no doubt to an insufficient number of comparisons required to demonstrate significant differences. Trends were in favor of the "R" method, however. The same was true of the comparisons in Table 2 where the 20° C continuous and the 30° C continuous methods were compared, and the trends were in favor of the 20° C continuous method. Possibly the method adopted by the Association of Official Seed Analysts of North America should be followed, namely, 18 hours at a lower temperature (20° C) and 6 hours at a higher temperature (30° C).

However when all four temperature methods were combined in a statistical analysis (Table 3), a significant difference was obtained between the "R" and "S" alternating temperature and between the 20° C and 38° C temperature methods. The significant interaction obtained in temperature methods versus substrata and moisture treatments indicates that, although temperature methods gave significantly different germination percentages and number of sprouts, respectively, different temperature methods reacted differently with different substrata and moisture treatments. In germination technic, therefore, the temperature method used must necessarily be tested with various substrata and moisture conditions in order to determine the most desirable set of conditions to give the best germination results.

In tests on seed ball size in relation to germination of sugar beet

seed (Table 4), the wide differences obtained in percentage germination and sprout counts (varying directly in proportion to seed ball size) critically indicate the need for thorough mixing of seed, mechanically if possible, to eliminate biased selection of the germination sample. The use of a Boerner grain sampler is essential to the securing of a representative sample. A test conducted on the germination of a specially prepared sample in which a 25-gram sample of seed was made up of percentage amounts by weight of 4.0 mm, 3.5 mm, and 2.5 mm size seed balls, showed this sample to germinate 85.56% compared to 84.88% for the random selected sample. This difference of 0.68% is non-significant. This demonstrates the reliability of the Boerner grain sampler or some other equally effective mechanical device in reducing the beet seed sample to desired size before commencement of a germination test.

To determine minimum length of germination period required for germination of sugar beet seed, a set of 40 samples of seed was germinated in quadruplicate in paper toweling and in sand using the "S" method of alternating temperatures (Table 9). Readings on germinated seed balls and number of sprouts were made on the 4th, 7th, 10th, and 14th day of the test. The results indicate that a period of 10 days is adequate for obtaining reliable germination readings on beet seed. In fact in the case of fresh seed, germinated at a temperature of 30° C, a 7-day period may be adequate under certain conditions (Table 10). In this particular study a 4-, 7-, 10-, and 14-day germination period was used, with sand, soil, and blotting paper as the substrata. Of special interest was the vigor of seedlings in the greenhouse soil test where practically all of the germination was completed at the end of the seventh day. It would seem that for practical field purposes the germination count obtained on most germination tests in the field at the end of 7 days is the important consideration from the standpoint of producing vigorous seedlings of uniform size. Apparently, greater emphasis should be placed on vigor and condition of seedlings, than relying entirely on percentage germination as a sole index of acceptability of seed.

In the conduct of the 336 separate germinations comprising the 84 tests in Series A, three types of substrata, paper toweling, blotting paper, and sand were used. It was found that germination and sprout counts could be made on an average 30% or more faster with either paper toweling or blotting paper as a substratum than when sand was employed. Further, sprout counts were made with much greater ease and accuracy. Also, it was observed that counts could be delayed for a day or two with the paper toweling or blotting paper without entailing too great an additional outlay in time in making the readings. With sand, such delay caused the sprouts to become tangled, necessitating much additional work in making the required counts. In comparing the three types of substrata (Table 5), it is noted that the percentage germination and number of sprouts is practically the same for both the paper toweling and blotting paper and significantly lower for the sand. While the advantage for the two types of substrata is definitely indicated, there is an apparent advantage for the sand method in the

production of somewhat better conditioned and more vigorous sprouts. This is not sufficient, however, to establish its preference over the paper toweling or blotting paper methods.

Forty-two tests each were made with two lots of fresh beet seed, one presoaked for 2 hours prior to germination and the other dry, to determine the effect of pretreatment on germination (Table 6). On this particular lot of seed, no apparent benefit was obtained from pretreatment of seed. However, on beet seed of different ages, a noticeable increase was obtained in rate of germination and percentage increase in germination over dry seed in a test conducted in 1935 (Table 11). It would appear from the experience of these tests that possibly the greatest value in the pretreatment of seed lies in the fact that the substratum can be kept a little drier during the period of the test, the seed starts to swell and germinate more quickly, and molds do not have as favorable a medium in which to multiply, compared to general procedure when dry seed is used for the germination test.

Owing to large differences in quality of water, a study was made of the tap and distilled water used for presoaking the seed in these tests. The results shown in Table 7 indicated no significant difference for either kind of water as used in these tests. Similarly, a study designed to test the effect of these waters on moistening the substratum (Table 8) showed no appreciable difference in favor of one or the other water used in these tests. The conclusion seems warranted, therefore, that under the conditions of this test there was no advantage in using distilled water when tap water was available of the quality described earlier in this paper.

#### SUMMARY

Tests in quadruplicate were conducted with sugar beet seed to determine effects of variable and constant germinating temperatures, four seed ball sizes, three kinds of substrata, presoaking treatment of seed using tap and distilled water, and 4-, 7-, 10-, and 14-day periods of germination on percentage germination and number of sprouts from representative 100 seed ball samples of seed.

The 20° C continuous method and a method designated as "R" in which was maintained a temperature of 30° C for the first 24 hours alternating with a temperature of 20° C for 16 hours and 30° C for 8 hours for the balance of the test, were productive of somewhat better results than the 30° C continuous method and the standard of alternating temperature at 20° C for 16 hours and 30° C for 8 hours.

Seed ball size was positively correlated with germination. The larger seed balls produced the higher germination and larger number of sprouts.

To secure representative samples, the use of a mechanical grain sampler, such as the Boerner sampler, is necessary.

Paper toweling and blotting paper were found preferable to sand as a germination bed.

No significant differences were obtained for presoaking of fresh seed. On older seed, this treatment appears to have some merit.

Reporting germinating results at the end of a 10-day period seems warranted.

Attention is called to more general consideration of seedling vigor in determining acceptability of seed.

Supplementing germination tests with field tests appears a desirable procedure.

#### CONCLUSIONS

The results of tests discussed in this paper indicate the need of a random sample of beet seed mechanically reduced to proper sample size; presoaking seed, especially older seed; the choice of either paper toweling or blotting paper; reporting results of tests at the end of 10 days; and supplementing laboratory tests with field tests wherever possible so as to determine vigor of seedling plants. Germinating beet seed at colder temperatures appears desirable. The tentative choice of a 20° C continuous temperature seems warranted by these tests. Further work on this point is necessary to establish the best temperature method.



## DIFFERENTIAL FEEDING OF GRASSHOPPERS ON CORN AND SORGHUMS<sup>1</sup>

ARTHUR M. BRUNSON AND REGINALD H. PAINTER<sup>2</sup>

SEVERE outbreaks of insects offer unusual opportunities for studies of their habits, especially in respect to food preferences, and for studies of differential injury between varieties and between related species of crop plants. The grasshopper outbreak of 1936 afforded such an opportunity. The observations presented below are recorded now because of their interest to agronomists and entomologists and because outbreaks offering the possibility of obtaining similar information do not occur with any regularity. Special methods of controlled infestation or trials in localities where grasshoppers are perennially abundant might permit continued and valuable studies.

### REVIEW OF LITERATURE

Many agronomists and entomologists think of grasshoppers as a menace to any and all crops, although the literature (1, 3, 4, 5, 6, 8, 10, 11)<sup>3</sup> contains scattered references to the contrary. The 1936 grasshopper outbreak in Kansas was characterized by the wide difference between injury to corn and to sorghums. Such a difference was first noticed by Riley (8) nearly 60 years ago during the early outbreaks of the Rocky Mountain locust and has been mentioned (3) subsequently on a few occasions.

The cause of this preference for corn is unknown but may be a specific characteristic of certain American *Acrididae* since Uvarov (11) records an Asiatic species (*Colemania spharioides* I. Bd) that feeds chiefly on sorghums. It has been shown (7) in the case of some insects that longevity and fecundity are dependent upon specific food plants. It is possible that the decided preference of Kansas grasshoppers for corn and their aversion to the sorghums may be related to their inability to utilize these two plants to equal advantage in metabolism.

### MATERIALS AND METHODS

Most of the observations herein reported were made in the yield test plats of the cooperative corn project on the Agronomy Farm of the Kansas Agricultural Experiment Station at Manhattan, Kansas. The different strains of corn were grown in plats two rows wide and ten hills long and each strain was replicated five times in randomized order. Observations also were made in the sorghum nursery at Manhattan and in many farm fields in eastern and central Kansas.

In the corn breeding nursery the grasshoppers were mostly *Melanoplus differentialis* (Thomas) and *M. bivittatus* (Say). Although many grasshoppers were killed by applications of poison bait and by Sarcophagid parasites of the

<sup>1</sup>Joint contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Kansas Agricultural Experiment Station, Manhattan, Kans. Contribution No. 272 of the Department of Agronomy and No. 452 of the Department of Entomology, Kansas Agricultural Experiment Station. Received for publication January 6, 1938.

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<sup>3</sup>Figures in parenthesis refer to "Literature Cited," p. 345.

adult grasshoppers, enough remained to produce severe injury. No exact count of numbers was attempted, but they were estimated to average about five individuals per stalk of corn. A continual movement of the insects over the field tended to give reasonably uniform distribution. Most of the damage took place over a period of approximately three weeks beginning the first of July.

The percentage of leaf surface destroyed by grasshoppers was estimated independently by three observers for each plat. The average of the three estimates was used as the individual plat figure, so with the five replications of each strain the final value represents a mean of 15 separate estimates. Considering that the three individuals making the estimates worked entirely independently, their readings were remarkably consistent. The mean percentage defoliation recorded by each observer for the 931 plats is as follows: D.A., 19.10; W.H.F., 18.46; R.C.P., 18.21; Mean, 18.59.

The estimates of damage to the Manhattan plats here reported were made during the period July 27-31, 1937. The data obtained were subjected to the analysis of variance (2, 9). Generalized standard errors from the analysis of variance are not shown because of the wide range of means in each table and the tendency toward correlation between means and errors. Further reference to individual standard errors is made in the following detailed discussion.

#### EXPERIMENTAL DATA

The extreme range of defoliation observed in the experimental corn plats at Manhattan was from 3% to 73%. In the four experiments here reported the range for 122 varieties and hybrids was from 4.0% to 59.8%. As will be shown later in the statistical analyses, there was a significant difference due to place effect in some instances. In general, however, the infestation was reasonably uniform and differences due to location were much less than those due to variety. The variety Pride of Saline occurred in four experiments with slightly different planting dates and located in different parts of the experimental area. In three of these the average estimated injury was 12% and in the fourth 18%. Boone County White occurred in two different experiments, giving average estimated injuries of 22% and 23%, respectively. Within an experiment and often in contiguous plats sharp and consistent differences could be seen between different varieties and strains.

Two types of damage by grasshoppers were evident and each appeared characteristic of certain strains. In the case of Pride of Saline, and certain other varieties and hybrids, the injury consisted mainly of destruction of the tender portions of the leaf blade, leaving the bare midrib. In other strains the grasshoppers cut off the entire leaf at the collar where it is joined to the leaf sheath. Occasionally the pruned leaf was eaten, but in the majority of cases it dried on the ground untouched, while the grasshoppers ate part of the leaf sheath remaining on the plant. The plants within an individual hybrid were more uniform for the type of injury exhibited than were those within an open-pollinated variety. A field of an open-pollinated variety of corn defoliated by grasshoppers and exhibiting both kinds of leaf injury is shown in Fig. 1.

## OPEN-POLLINATED VARIETIES

The injury to 16 open-pollinated varieties and strains is shown in Table 1. Four strains of Midland varied from 8.8% to 11.0% defolia-



FIG. 1.—Corn field defoliated by grasshoppers. Note that on many plants the sides of the leaf blade have been eaten leaving the midribs intact, while on others the entire leaf has been cut off at the collar and may be seen on the ground.

tion. Five strains of Kansas-grown Reid Yellow Dent varied from 24.0% to 31.4% injury and were the worst injured of the open-pollinated varieties tested. Unfortunately, no unadapted variety from out of the state was represented in this series which probably accounts for the fact that all varieties have fairly low injuries compared with unadapted hybrids listed below. The analysis of variance indicates that the differences between varieties with respect to grasshopper defoliation are highly significant. Standard errors for the individual varieties range from 0.86 to 3.85, although most of them lie between 1.00 and 2.00 and only two are above 2.07. Differences of 5% to 7% in defoliation nearly always indicate significant varietal differences. All strains of Midland are significantly different in grasshopper injury from all strains of Reid Yellow Dent. In this experiment the differences between replications are not statistically significant.

Many fields of open-pollinated varieties of corn exposed to grasshopper injury in the central and eastern part of the state were examined. In all of these fields rather pronounced variation in injury to individual plants was noted. Some plants would be almost completely

TABLE 1.—*Estimated percentage defoliation of open-pollinated varieties of corn at Manhattan, Kansas, in July 1936, each observation being a mean of estimates by three independent observers.*

Rank	Variety	Origin of seed, Kansas county	Days from planting to pollen shedding	Estimated defoliation, %					
				Ser. 1	Ser. 2	Ser. 3	Ser. 4	Ser. 5	Mean
1	Cassel	Greeley	65	8	7	12	5	6	7.6
2	Hays Golden	Thomas	65	10	8	9	7	5	7.8
3	Midland	Anderson	71	13	10	5	7	9	8.8
4	Colby Yellow Cap	Thomas	65	13	9	8	6	10	9.2
5	Midland	Osage	72	12	11	7	10	7	9.4
6	Muth Red	Mitchell	68	9	6	9	8	15	9.4
7	Midland	Allen	72	15	6	12	12	7	10.4
8	Midland	Coffey	73	12	12	13	8	10	11.0
9	Yellow Selection No. 1	Chase	72	9	18	13	9	7	11.2
10	Pride of Saline	Riley	72	8	8	15	10	17	11.6
11	Commercial White	Allen	78	22	17	18	23	20	20.0
12	Reid Yellow Dent	Brown	69	22	27	23	30	18	24.0
13	Reid Yellow Dent	Atchison	70	28	30	25	23	22	25.6
14	Reid Yellow Dent	Brown	69	23	30	35	18	30	27.2
15	Reid Yellow Dent	Doniphan	70	32	27	27	28	32	29.2
16	Reid Yellow Dent	Brown	68	38	35	30	37	17	31.4

Analysis of Variance					
Source of variation	Degrees of freedom	Sum of squares	Mean square	F	Significance
Total.....	79	6705.49			
Between varieties.....	15	5652.29	376.82	23.02	Highly significant
Between replications.....	4	71.93	17.98	1.10	Not significant
Remainder, error.....	60	981.28	16.35		

defoliated before surrounding plants were severely injured, and at the other extreme, occasional plants would still show little injury when nearby plants were stripped. Photographs of such contrasts in a field of Hays Golden, near Manhattan, are shown in Figs. 2 and 3. In cases



Fig. 2.—A relatively grasshopper-resistant plant in a field of Hays Golden corn showing little injury after surrounding plants had been nearly defoliated.

of only moderate infestation such resistant plants frequently would survive and produce a little seed, but in areas of severe infestation no corn plant was observed which did not eventually succumb.

#### KRUG TOP CROSSES

In Table 2 are presented the estimated injury to 19 early top crosses together with that of the common pollen parent; Krug Yellow Dent. The inbred parents originated in five states from varieties adapted to local environments. It will be noted that the only two entries from Kansas rank first and third for resistance to grasshopper injury. Here again the analysis of variance shows the differences in grasshopper injury between varieties to be highly significant, but differences between replications to be not significant. Standard errors calculated individually for these top crosses range from 0.24 to 3.52 with nine above 2.00 and four above 3.00. Most differences of 6% to 8% in defoliation are statistically significant.

#### BOONE COUNTY WHITE TOP CROSSES

In Table 3 are shown the estimated defoliation of a similar series of 32 top crosses from later inbreds, together with two open-pollinated

varieties. The six entries from Kansas inbreds rank 1, 2, 5, 6, 15, and 21 which is appreciably higher than would be expected from a random selection. The analysis of variance indicates that differences between varieties and between replications are both highly significant. The significance is much greater, however, between varieties than between replications. Standard errors of the individual entries range from 0.81 to 5.94 with 10 below 2.00 and 7 above 4.00. In general, differences of 8% to 10% are statistically significant.



FIG. 3.—Variability of individual plants of an open-pollinated variety of corn (Hays Golden) in susceptibility to grasshopper damage. Note the completely defoliated plant in the center as contrasted to the slightly injured one immediately to the left.

#### HYBRIDS

Table 4 contains the estimated injury for a series of 52 hybrids. Of these, 35 (those whose parent inbreds are designated by PS) originated from Kansas lines. These Kansas hybrids were strikingly resistant to grasshopper injury as compared to most out-of-state hybrids. In contrast, the lowwealth hybrids are grouped at or near the bottom of the list when ranked in order of severity of injury. The analysis of variance shows that differences between varieties and between replications are both highly significant, but, as in Table 3, the significance of differences between varieties is much greater than that between replications. Standard errors of the means of the various hybrids range

from 0.55 to 7.77. In almost all cases differences of 10% to 12% are statistically significant. In the lower ranges of injury (the upper half of the table), much smaller differences are statistically significant because of the smaller errors.

TABLE 2.—*Estimated percentage defoliation of Krug uniform top crosses by grasshoppers at Manhattan, Kansas, in July 1936, each observation being a mean of estimates by three independent observers.*

Rank	Inbred parent	Days from planting to pollen shedding	Estimated defoliation, %					
			Ser. 1	Ser. 2	Ser. 3	Ser. 4	Ser. 5	Mean
1	Kans. YS 51	67	4	4	5	5	5	4.6
2	Ohio 47	68	4	5	4	12	8	6.6
3	Kans. YS 48	67	4	4	10	8	11	7.4
4	Ind. T 92	67	10	7	7	4	12	8.0
5	Ind. Tr.	66	11	5	8	8	10	8.4
6	Ia. OS 426	67	5	5	10	13	9	8.4
7	Ohio 56	68	16	12	6	15	22	14.2
8	Ia. L289A2	66	8	19	12	16	20	15.0
9	Ind. B <sub>2</sub>	67	12	15	17	13	20	15.4
10	Ind. Palin 8	67	15	15	12	18	17	15.4
11	Ill. Hy 8	67	21	13	10	18	20	16.4
12	Ill. 5120	68	21	13	12	20	18	16.8
13	Krug	67	18	13	17	16	20	16.8
14	Ohio 61	68	30	13	15	18	12	17.6
15	Ill. D 8	68	17	20	14	17	27	19.0
16	Ohio 10	67	10	30	20	13	22	19.0
17	Ia 234	66	22	22	18	31	10	20.6
18	Ind. WF9	66	20	23	27	17	23	22.0
19	Ia. 224A <sub>2</sub>	67	28	19	12	30	23	22.4
20	Ia. I 198	66	28	27	17	28	22	24.4

#### Analysis of Variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	F	Significance
Total.....	99	5049.36	—	—	—
Between varieties.....	19	3220.56	169.50	7.87	Highly significant
Between replications....	4	191.56	47.89	2.22	Not significant
Remainder, error.....	76	1637.24	21.54	—	—

#### SORGHUMS

Perhaps the most striking contrasts in injury by grasshoppers were observed between corn and sorghums. In only very rare cases was anything approaching commercial damage seen in sorgos or grain sorghums. Adjacent fields of corn and sorghum, in heavily infested areas, invariably showed severe injury to or destruction of the corn, with little or no damage to the sorghum. Such an instance is illustrated in Fig. 4. Isolated sorghum plants growing as volunteers in corn fields remained almost untouched after the surrounding corn was completely stripped. On the other hand, single volunteer corn stalks in fields of sorghum were sought out and destroyed. In areas where both



crops are adapted, such a marked contrast would justify the substitution of grain sorghums for at least part of the acreage of corn in seasons when grasshopper egg counts indicate the probability of a severe infestation.

Observations in a sorghum nursery showed slight but consistent

TABLE 3.—*Estimated percentage defoliation of Boone County White uniform top crosses by grasshoppers at Manhattan, Kansas, in July 1936, each observation being a mean of estimates by three independent observers.*

Rank	Inbred plant	Days from planting to pollen shedding	Estimated defoliation, %					
			Ser. 1	Ser. 2	Ser. 3	Ser. 4	Ser. 5	Mean
1	Kans. PS 54	75	7	5	4	4	8	5.6
2	Kans. PS 55	76	3	7	7	12	6	7.0
3	Ky. 41	75	8	7	5	9	12	8.2
4	Tenn. 8-6	76	6	5	6	12	13	8.4
5	Kans. YS 55	74	7	9	10	7	13	9.2
6	Kans. YS 53	75	8	8	7	15	9	9.4
7	Pride of Saline	71	12	5	10	12	23	12.4
8	Ind. Tr	72	8	10	10	18	17	12.6
9	Ill. KM 2	74	10	11	12	13	23	13.8
10	Mo. R 104 C	71	13	18	7	27	10	15.0
11	Tenn. 7-6	74	12	8	23	12	20	15.0
12	Ill. R4	72	17	8	15	10	25	15.0
13	Ind. 3 VP	74	17	12	13	23	10	15.0
14	Ohio 47	72	18	12	15	20	18	16.6
15	Kans. YS 58	72	13	15	22	17	17	16.8
16	Ind. Palin 8	72	12	17	28	8	20	17.0
17	Ill. 5120	72	17	18	12	22	22	18.2
18	Ohio 67	71	10	16	27	12	33	19.6
19	Ia. MC 401	71	22	7	18	15	40	20.4
20	Ky. 21	78	28	21	20	15	18	20.4
21	Kans. YS 75	73	23	12	18	20	32	21.0
22	Ind. R 94	72	12	25	23	20	28	21.6
23	Boone Co. White	73	31	22	10	18	30	22.2
24	Mo. J 33 C	74	24	18	27	18	30	23.4
25	Ky. 30a	74	20	12	13	40	37	24.4
26	Ia. L317 C	72	18	20	25	32	32	25.4
27	Ky. 39a	75	27	25	23	27	26	25.6
28	Richey 119-11a	75	37	15	40	32	28	30.4
29	Tenn. JGP 7-2	74	23	20	45	28	42	31.6
30	Ohio 01	69	42	28	40	42	28	36.0
31	Tenn NP 10-1	74	40	27	38	50	30	37.0
32	Ill. Hy	72	28	38	37	32	50	37.0
33	Tenn. 18-4	76	35	28	33	48	42	37.2
34	Ky. 27	74	53	40	43	25	38	39.8

#### Analysis of Variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	F	Significance
Total	169	21911.11			
Between varieties	33	15135.51	458.65	10.68	Highly significant
Between replications	4	1104.32	276.08	6.43	Highly significant
Remainder, error	132	5671.28	42.96		



TABLE 4.—*Estimated percentage defoliation of miscellaneous corn hybrids at Manhattan, Kansas, in July, 1936, each observation being a mean of estimates by three independent observers.*

Rank	Hybrid	Days from planting to pollen shedding	Estimated defoliation, %					
			Ser. 1	Ser. 2	Ser. 3	Ser. 4	Ser. 5	Mean
1	(PS 21 X PS 36) X PS 7854	74	3	4	4	6	3	4.0
2	(PS 48 X PS 55) X (PS 8 X PS 11)	67	5	8	10	5	5	6.6
3	(PS 8 X PS 18) X (PS 4 X PS 14)	69	6	7	5	10	7	7.0
4	(PS 26 X PS 39) X (PS 7852)	74	4	3	13	10	5	7.0
5	(PS 41 X PS 54) X (PS 48 X PS 55)	65	4	8	5	13	10	8.4
6	(PS 29 X PS 36) X (PS 4 X PS 14)	70	5	12	13	6	9	9.0
7	(PS 29 X PS 36) X (PS 26 X PS 34)	71	5	12	7	5	17	9.2
8	(PS 44 X PS 54) X (PS 8 X PS 17)	67	4	17	7	13	10	10.2
9	(PS 41 X PS 54) X (PS 8 X PS 18)	67	8	17	8	6	15	10.8
10	(PS 48 X PS 55) X (PS 4 X PS 14)	67	12	17	8	10	7	10.8
11	(PS 8 X PS 11) X (PS 4 X PS 14)	68	10	7	9	20	9	11.0
12	(PS 29 X PS 36) X PS 34	69	8	22	8	8	12	11.6
13	Pride of Saline X (PS 4 X PS 14)	68	12	15	8	10	15	12.0
14	(PS 41 X PS 54) X (PS 4 X PS 14)	66	7	23	10	8	15	12.6
15	(11b X 61) X (23 X 24)	73	6	20	14	13	11	12.8
16	(PS 10 X PS 17) X (PS 4 X PS 14)	66	15	18	8	7	17	13.0
17	(PS 44 X PS 54) X (PS 4 X PS 14)	67	7	12	15	18	13	13.0
18	(PS 10 X PS 18) X (PS 4 X PS 14)	67	8	22	18	8	10	13.2
19	(PS 5 X PS 18) X (PS 4 X PS 14)	68	7	20	13	13	15	13.6
20	(PS 8 X PS 17) X (PS 4 X PS 14)	67	20	15	13	8	12	13.6
21	(PS 41 X PS 55) X (PS 48 X PS 51)	64	5	10	17	15	25	14.4
22	(PS 48 X PS 51) X PS 55	67	20	7	15	8	25	15.0
23	(PS 24 X PS 39) X (PS 4 X PS 14)	68	4	28	13	15	18	15.6
24	(PS 6 X PS 18) X (PS 4 X PS 14)	67	8	22	30	11	8	15.8
25	(PS 41 X PS 55) X (PS 8 X PS 11)	67	12	13	27	20	15	17.4
26	(PS 5 X PS 11) X (PS 4 X PS 14)	68	12	11	22	15	28	17.6
27	(PS 10 X PS 11) X (PS 4 X PS 14)	64	7	18	30	15	18	17.6
28	Pride of Saline (Open-pollinated)	69	8	27	12	13	30	18.0
29	(PS 41 X PS 55) X (PS 10 X PS 17)	63	13	23	18	13	28	19.0
30	(PS 41 X PS 55) X (PS 5 X PS 19)	66	15	18	17	20	28	19.6

31	(PS 41 × PS 53) × (PS 8 × PS 18)	68	13	23	30	17	20	20.6
32	(11 a × 67) × (23 × 24)	69	14	14	27	28	20	20.6
33	(PS 41 × PS 53) × (PS 4 × PS 14)	67	15	30	20	23	22	22.0
34	(11 a × 23) × (41 × 43)	71	13	30	21	35	15	22.8
35	(PS 5 × PS 19) × (PS 4 × PS 14)	67	13	23	35	27	25	24.6
36	(11 b × 23) × (41 × 43)	71	22	13	28	28	33	24.8
37	(PS 48 × PS 51) × (PS 10 × PS 17)	64	18	32	25	20	32	25.4
38	(PS 48 × PS 51) × PS II	64	27	38	20	25	23	26.6
39	(PS 5 × PS 18) × PS 7844	69	13	17	40	40	38	29.6
40	(PS 41 × PS 53) × PS II	65	22	32	38	32	37	32.2
41	Lowleath Hybrid D	64	32	27	58	30	28	35.0
42	Lowleath Hybrid 3594	66	23	37	52	42	33	37.4
43	Lowleath Hybrid CR	67	40	38	47	35	28	37.6
44	(A × L) × (Hy × R4)	64	25	45	48	28	42	37.6
45	(A × Tr) × (R4 × Hy)	67	45	48	28	42	35	39.6
46	(A × L) × (I 234 × I 289)	61	47	35	52	48	42	44.8
47	Lowleath Hybrid CC	65	60	48	32	48	38	45.2
48	Lowleath Hybrid CI	62	57	45	60	38	47	49.8
49	Lowleath Hybrid AQ <sub>2</sub>	65	45	75	57	33	37	50.0
50	Lowleath Hybrid CX	64	48	50	52	42	62	50.8
51	Lowleath Hybrid A <sub>2</sub>	62	57	57	60	43	43	52.0
52	Lowleath Hybrid C	63	70	52	57	57	63	59.8

## Analysis of Variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	F	Significance
Total	259	62,832.69			
Between varieties	51	51,284.29	1,005.57	19.79	Highly significant
Between replications	4	1,181.52	295.38	5.81	Highly significant
Remainder, error	204	10,366.88	50.82		



FIG. 4.—Adjacent fields of sorghum and corn. The sorghum plants (left) are scarcely touched while the corn plants (right) are rapidly being defoliated.

differences in grasshopper injury to different varieties. In general, injury to the sorghos and the kafirs was less than to milo and to some of the newer varieties originating from hybrids involving milo.

#### DISCUSSION

The striking contrasts in defoliation recorded in Tables 1 to 4 and the consistency of injury to individual hybrids or varieties in the various replications leave little doubt of a genetic basis for the differential injury recorded. Two other hypotheses, however, might be considered as possible explanations of the differences in injury to individual plants and strains of corn. It is known that grasshoppers tend to be gregarious, feeding on parts of the plants where sap is exposed by the feeding of other grasshoppers. While this habit may explain why certain plants escape in a general field, it will not explain the occurrence of consistent differences between strains occurring through several replications. A second possible explanation might be based on differences in maturity of plants. Although it was noticed that two plantings of the same corn on different dates sometimes differed in the amount of injury by grasshoppers, no consistent relationship between injury and time of flowering of strains planted at the same time could be found. Except in the open-pollinated varieties, as shown in Table 1, comparatively small differences in flowering dates were represented in any one test. It is the opinion of the authors that neither the gregarious instincts of the grasshoppers nor differences in maturity of the tested strains was of importance in determining the differential injury noted. Heritable differences in resistance to grasshopper injury may be worth consideration in corn improvement programs in regions which have frequent grasshopper outbreaks.

The Kansas inbred lines involved in the top crosses and hybrids reported on have come from varieties adapted to a grasshopper-infested environment where occasional severe outbreaks have been experienced. Under these conditions and with the variability in corn illustrated in Figs. 2 and 3, it would seem reasonable to assume that natural selection has operated to eliminate the variants most susceptible to grasshopper injury and to favor the propagation of local varieties from the most grasshopper-resistant individuals. Complete immunity has not been attained, it is true, but rather striking differences have been developed. Neither has complete immunity from the harmful effects of high temperature or of insufficient moisture been attained, but the hardy varieties of corn from the southwestern Great Plains can endure these severe conditions much better than the varieties native to Iowa or Illinois. Adaptation to environment in naturally cross-fertilized species is the gradual and cumulative result of natural selection, and it seems entirely reasonable to assume that it may include in many cases the building up of resistance to native insect enemies.

#### SUMMARY

1. In the grasshopper outbreak of 1936 outstanding instances of differential injury among corn varieties, top crosses, and hybrids were noted. In one series of 52 hybrids, defoliation ranged from 4.0% to 59.8% as averages of five randomized replications.

2. Extreme contrasts between grasshopper injury of corn and of sorghums were noted. In some cases corn in one field was eaten to the ground while sorghum in an adjacent field was practically uninjured. Although all sorghums show considerable resistance, the sorgos and kafirs were injured less than milo and milo derivatives.

3. As a rule, the varieties and inbred lines of corn showing the greatest resistance originated in areas where grasshoppers are a natural element of the environment. It is suggested that natural selection operating in the development of adapted varieties of corn has tended to intensify resistance to grasshoppers and to other natural insect pests of the region.

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## NOTES

### A DWARF OAT FOUND IN A NOTEX-VICTORIA CROSS<sup>1</sup>

AN interesting dwarf oat plant was found in 1934 in a mass hybrid planting in the sixth generation of the cross, Nortex x Victoria, at Texas Substation No. 6, Denton, Tex. The cross was made by F. A. Coffman, Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.



FIG. 1.—Rows of Victoria oats (left), dwarf (three center rows), and Nortex (right).



FIG. 2.—Panicles and spikelets of Nortex (left), dwarf oat (center), and Victoria (right).

The dwarf strain has been grown three seasons and continues to breed true. The dwarf plants (Figs. 1 and 2) are about half the height of Nortex, the shorter of the two parents. The culms are rather thick, stiff, and strong; the panicle is very short and compact; the florets are short and plump, with outer glumes frequently wanting; awns are very short and weak, or absent, in contrast

<sup>1</sup>Technical Series No. 446, Texas Agricultural Experiment Station.

to the rather long, prominent awns of both parents. The dwarf strain is moderately resistant to crown rust, although not so resistant as the Victoria parent. It has not been tested for resistance to smut.

Although several attempts to cross this strain with other oats have been made by Mr. Coffman, no seed has been obtained. Additional attempts will be made to cross it on normal oats. It may possibly be of value in breeding to reduce plant height and awn size and to improve the strength of stem.

In panicle and spikelet characters this dwarf oat somewhat resembles the so-called "Trelle dwarf" reported by Derick.<sup>2</sup>—I. M. ATKINS, *Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture*, and P. B. DUNKLE, *Texas Substation No. 6, Texas Agricultural Experiment Station*.

<sup>2</sup>DERICK, R. A. A new "dwarf" oat. *Sci. Agr.*, 10: 539-542. 1930.

#### GUMMED-PAPER TAPE FOR SPACE-PLANTING WHEAT

A METHOD is described for space-planting wheat or other small grains by the use of a contrivance for placing the seeds at desired intervals on gummed-paper tape before seeding time. The rolls of tape are planted with a New Columbia Planter using a simple spool and shoe attachment. The necessary materials usually may be found around any agronomy department or purchased for less than \$10. Plans for this planting method were developed after consultation with W. J. Sando of the Division of Cereal Crops and Diseases and Olaf Gronaas of the North Dakota Agricultural Experiment Station.

Garden seeds glued to a "seed tape" have been on the market for more than 20 years. The machine used in applying the seeds to the glue-coated tape, however, was not adapted to the small numbers of seeds planted in individual nursery rows, and a machine for planting the tape was not available.

Space-planting of seed often is necessary where the mature plants are to be separated and studied individually. It is also useful when the number of seeds is limited and maximum yield per plant is required. The quantity of seed that can be space-planted ordinarily is limited by the time and help available for dropping individual seeds by hand. A stand supporting a planting board with holes bored at suitable intervals for dropping individual seeds into the furrow has eliminated stooping but has not been usable in windy weather, and even under optimum conditions two men could plant only about 30 17-foot rows per hour. A cylinder for the Columbia planter with small shallow holes can be used to plant rapidly 70 to 80 kernels per row if the seeds are of uniform size, but often two seeds fall together in the row, and satisfactory separation of the plants at harvest is not possible.

Probably the most satisfactory solution of the problem has been presented by Vogel<sup>1</sup> who used a drill with a seed cup having a conical center turning in a horizontal plane. The kernels fall into individual

<sup>1</sup>VOGEL, O. A. Three-row nursery planter for space and drill planting. *Jour. Amer. Soc. Agron.*, 25: 426-428. 1933.



pockets in the bottom of the cup and any extra kernels are swept off by a brush riding above the opening at the moment of dropping through. When the seed is of uniform size, Vogel's drill is preferable to gummed paper because it requires less labor. This drill, however, is unsuitable in the durum wheat breeding program at Fargo, where several different kernel types and shapes are involved and where rust and heat have caused many strains to be more or less shriveled.

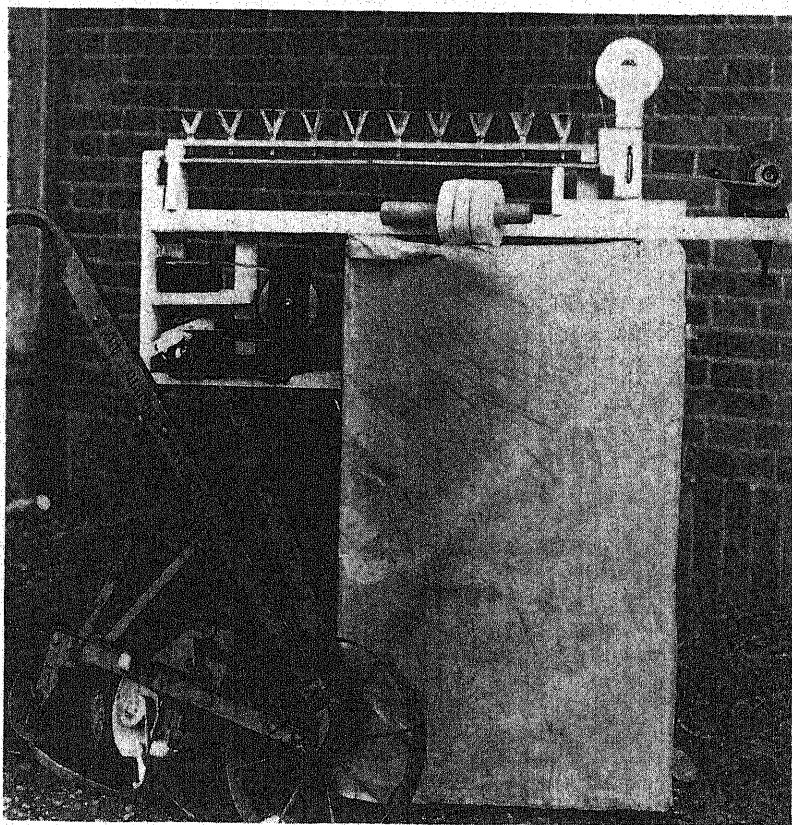


FIG. 1.—"Tape spacer" and New Columbia Planter with space-planting slide and spool attached. Also  $\frac{3}{4}$  roll of toilet tissue on spindle after having been cut on wood lathe.

The tape-spacer for sticking the seed on gummed 1-inch tape is illustrated in Fig. 1. A half-turn of the crank moistens a 30-inch strip of tape and a kernel is then dropped through each of the 10 funnels onto the gummed paper. The machine then covers the kernels with a one-inch strip of toilet tissue, presses the tissue and gummed tape together, and rolls up the strip usually into 17-foot lengths.

A drawing of the tape-spacer is shown in Fig. 2. This drawing differs from the photograph in Fig. 1 in that the tape moistener has



been placed nearer the funnels so all the tape under the funnels at one time is freshly wet.

The gummed-paper roll is held in an ordinary moistener stand, but instead of the metal roller ordinarily used for gummed tape, an office letter moistener consisting of a small brush inverted in water contained in a small metal dish is used to effect more uniform moistening. The tape passes around a spool which turns the gummed side up so that the kernels can drop through the funnels onto the sticky surface. The kernels are sealed in position by the toilet tissue which is pressed against the gummed surface in passing between two rollers covered with sponge rubber weather stripping. Tension on the rolls is main-

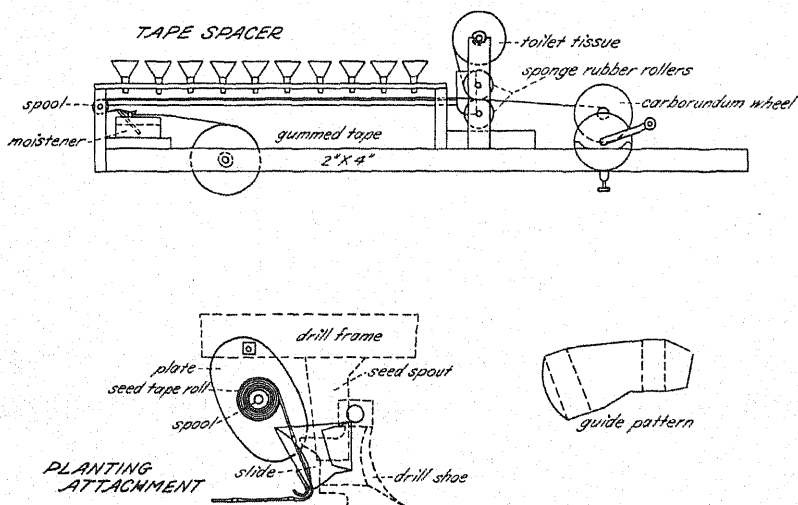


FIG. 2.—Design of "Tape spacer" for dropping spaced seeds and rolling up gummed tape. Also planting attachment for use with New Columbia Planter. Regular drill parts are dotted in.

tained by rubber bands between  $\frac{1}{4}$ -inch bolt axles. The tape is rolled up on a 1-inch composition bottle cap (from a mouth-wash bottle) fastened by a nut to the shaft of an ordinary hand-turned carborundum wheel. Although a cheaper winding device might be made, such a grinder usually is available, and has the advantage of being geared so that half a turn of the handle is sufficient to wind 30 inches of tape. A wire (straightened paper clip) is attached to the shaft and bent outward along the face of the spool roller, and the folded end of the tape is hooked to this wire before starting the winding. The base of the tape-spacer is made of 2- by 4-inch lumber.

When 3-inch spacing is used, 10 seeds are dropped and rolled up at a time, making seven sections for a 17-foot row. If more than 30 inches of tape is wet at a time, the adhesive dries before the seeds can be covered. One-inch tape is preferable to greater widths because it is easier to cover in the furrow, while a tape narrower than 1 inch will

not hold the kernels satisfactorily. Spacings other than 3 inches may be used by making appropriate funnel stands.

Each rolled tape is pulled off the roller, the row number stamped on, and the end fastened with a paper clip. About 18 inches of blank tape are left at the numbered end for holding onto when starting to plant. A red pencil mark near the last kernel permits the ends of the rows to be kept in line.

The planting device, also illustrated in Figs. 1 and 2, consists of a free-turning spool attached to the frame, and a metal guide attached to the drill spout of a New Columbia Planter. The spool turns on a bolt attached by nuts to a heavy tin guard or plate, made from a large sardine can, which is bolted to the drill frame. The spool is tapered toward the outer end so as to receive the roll of tape readily. An empty adhesive tape spool held against the spool by rubber bands prevents the tape from flying off the spool as it unrolls. The guide which directs the unrolled tape into the furrow was cut from heavy galvanized iron. It hooks around the seed spout of the Columbia planter and is held by tightening the thumb screw of the regular drill shoe which fits over the guide and seed spout. The lip of the guide is bent around down and back to avoid cutting the paper and is close behind the drill shoe so the tape is placed in the bottom of the furrow before the soil falls back to cover it. The guide is open on the outer side so the tape may be slipped into place quickly. To load the drill for planting, one man raises the handles and the other holds back the spool cover, slips the tape over the spool, unrolls about 2 feet, and slips the tape over the guide. In planting, he holds the end of the tape so that the red mark indicating the first kernel matches the beginning of the row while the first man starts the drill and then lets go of the tape after 2 or 3 feet are covered with soil. At Fargo, where the soil is heavy, discs from the Planet Jr. cultivator outfit are attached to the Columbia planter for all nursery planting in place of the regular covering device.

The tape is planted with the tissue side up. The damp tissue offers practically no resistance to the emergence of the germinating seedlings.

Tissue in unperforated rolls 1 inch wide could not be purchased, so ordinary toilet tissue rolls ( $4\frac{1}{2}$  inches wide) were cut into four sections. Certain brands with light perforations were most satisfactory. A slightly tapered wood spindle (Fig. 1) which fitted tightly into a roll of paper was made in a wood turning lathe. A roll of tissue is placed on the spindle so that when turned in a lathe it will tend to wind up rather than unroll. The spinning roll is marked into four sections each  $1\frac{1}{8}$  inches wide with a soft or wax pencil, and then cut with a sharp butcher knife. It is necessary to work from the back of the lathe with the roll turning away from the knife so it will cut straight. The lathe should be run at the slowest speed. The four narrow rolls of tissue will cover 60 to 70 17-foot rows of tape. The ordinary rolls of gummed paper are long enough for about 40 rows of tape.

The total time required for the gummed-tape method of space-planting is about the same as that with the old method of direct hand planting, but about three-fourths of the work may be done inside and

during the winter. The tape-spacing operation may be done by two men at the rate of 35 to 40 17-foot rows per hour, and planting in the field by two men is accomplished at the rate of 100 to 150 rows an hour. The tape rolls may be planted in any weather when ordinary planting can be done. Planting with the Columbia planter using the regular cylinders may be done without detaching the spool and tape guide.

Wheat space-planted with gummed tape in 1936 and 1937 showed no indication of having been injured by the tape. However, one precaution must be observed. The tape must be covered more carefully in wet heavy soil than in ordinary planting. Evidently this is because of air spaces left which dry out the tape and prevent germination. If the soil is crumbly enough to pack well so that the tape is in direct contact with moist soil, no difficulty should be experienced. The paper soon rots in the field.

Aside from the advantage of speed, the tape method does not leave an open furrow exposed to drying air which frequently causes difficulty in obtaining uniform emergence by hand planting.—GLENN S. SMITH, *Division of Cereal Crops and Diseases, U. S. Dept. of Agriculture.*

#### CONSTRUCTION OF A DURABLE PASTURE CAGE

**S**MALL cages are widely used for making herbage yield determinations in a pasture that is being grazed. These cages must be light in weight so that in the field they may be easily moved, yet durable enough to prevent damage by the grazing animals. A cage that is both light and durable and that has been proved satisfactory by a season's use, is described here.

Most investigators in determining herbage yields use a cage that is 3 or 4 feet square. This often results in an extremely small yield of herbage from each plat. Mechanical errors of mowing or weighing,

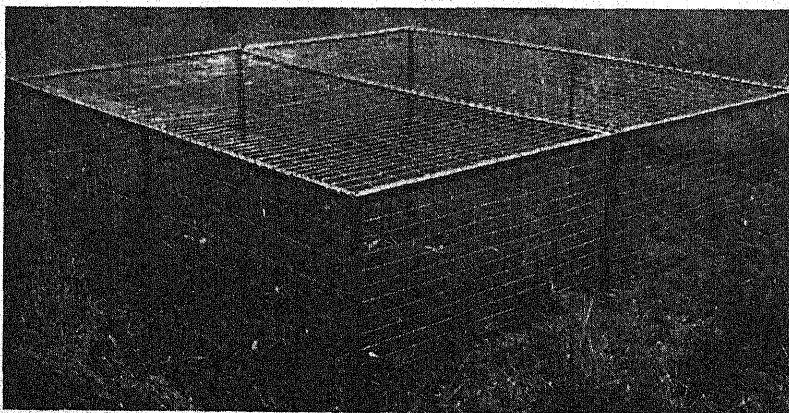


FIG. 1.—Cage assembled for field use.

which may occur when these plats are mowed with a power mower, will be greatly magnified if the yields are expressed on an acre basis. By increasing each side of the cage two-fold, the area harvested will be four times as large and the mechanical error from mowing will be

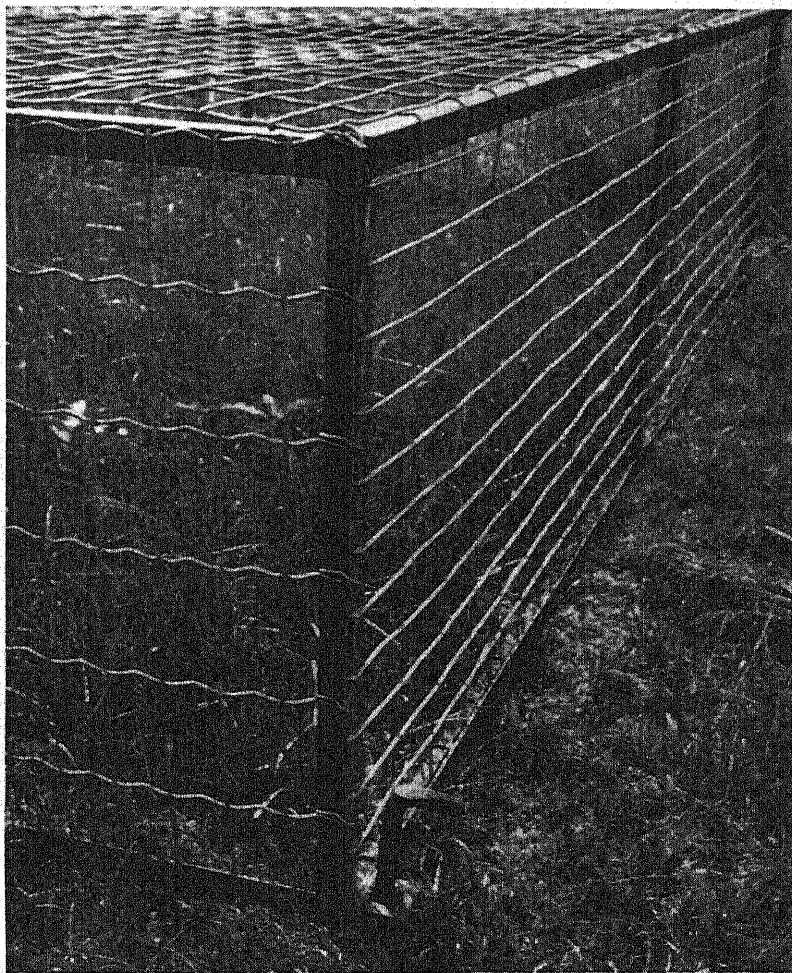


FIG. 2.—Method of staking down the cage.

reduced in proportion to the total herbage yield. For this reason the cages were constructed 8 feet square (Fig. 1). Cages of this size can be easily moved in the field and the increased size does not necessarily mean a reduction in the number of replications.

The framework of the cage was 1 inch x 1 inch x  $\frac{1}{8}$  inch black angle iron and painted with a lead paint. To facilitate transporting, each side

was made in a single section and the sections assembled and covered with wire in the field. Each section was made of welded angle-iron and the four sections bolted together at the corners to form the framework of the cage. One angle-iron brace was placed across the top of

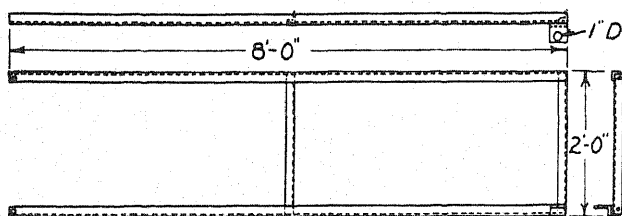
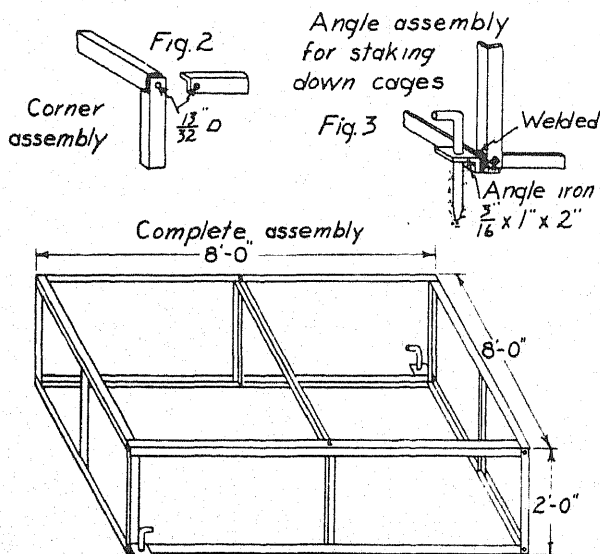


Fig. 1- Single section or side of cage



Material: Angle iron, black,  $1'' \times 1'' \times \frac{1}{8}''$   
 4 sections (angle assembly on two)  
 1 top brace  
 10 machine bolts -  $\frac{3}{8}'' \times \frac{3}{4}''$

FIG. 3.—Diagram showing construction of framework for cage.

the cage for additional bracing and to prevent the sides of the cage from being pulled together as the wire was stretched onto the frame. It also prevents the wire on the top of the cage from sagging. For staking down the cage a small angle-iron with a 1-inch hole was welded onto the framework at opposite corners of the cage (Fig. 2). Detailed construction of the framework is shown in the accompanying diagram (Fig. 3).

The cages were covered with electric weld, galvanized, woven wire, with horizontal and vertical wires size 11, and with mesh 2 inches x 4 inches. The heavy gauge wire was used to prevent grazing animals from tearing the wire by rubbing or by hooking it with their horns. The electric weld gives added bracing and prevents the wire from sagging between the places where it is fastened.

The construction cost of the cage framework was \$6.50 each. This included the materials, bolts for assembly, and one coat of lead paint. Cost of the electric weld wire as described was \$3.75 for each cage. A lighter weight wire may be purchased at a lower cost. To these costs must be added the labor cost of assembling the framework and attaching the wire.—J. M. POEHLMAN, *Division of Forage Crops and Diseases, U. S. Dept. of Agriculture and Missouri Agricultural Experiment Station.*

## SPINELESS CACTUS WINTERKILLS IN MONTANA

IN the search for plants that may prove of value in range reseeding or for emergency forage in Montana, some species are tried even though the probability of success is not very high. In April 1934, Superintendent W. H. Dameron of the Texas Agricultural Experiment Station substation at Sonora, Texas, kindly shipped for trial three sacks of vigorous-appearing internodes of a spineless cactus (*Opuntia ellisiana* Griff.)<sup>1</sup> to Miles City, Montana. These were planted at the U. S. Range Livestock Experiment Station<sup>2</sup> on April 24 in a previously dry-farmed field located adjacent to the Yellowstone River, but since used for range reseeding trials with a minimum of soil cultivation. A slit in the fine sandy-loam soil was opened with a spade, individual cactus "slabs" were inserted at varying inclinations, and the soil firmed back to cover the lower half of the cactus.

With only 5.51 inches of precipitation during the year, 3.53 inches of which occurred in the April-September period, 1934 proved to be the most severe drouth year in more than half a century of weather records at Miles City. Before the end of May, some growth was noted on about 10% of the slabs. Despite drouth, extreme heat, and the absence of soil cultivation, several of these slabs bloomed and more than half of them made some growth during the season and produced one to five new internodes each. Growth was noted during June and July when lack of available soil moisture forced most native range species into dormancy. Results of examinations on August 23 and November 2, 1934, are summarized in Table 1.

TABLE 1.—Results of tests of *Opuntia ellisiana*, 1934.

Number internodes planted	Number showing recent growth		Number blooming before	Number destroyed by rodents, cattle, etc., before		Number clearly dead on	
	Aug. 23	Nov. 2		Aug. 23	Nov. 2	Aug. 23	Nov. 2
166 100%	67 40.4%	84 50.6%	22 13.3%	3 1.8%	21 12.7%	32 19.3%	35 21.1%

Between April 24 and November 2, the lowest temperature recorded at Miles City was 23° on November 1. Minimum temperature ranged from 24° to 30° on the five preceding days. The cactus appeared to have survived this frosty weather with little damage. About two-thirds of the total number were covered on November 2 with a straw mulch to a depth of 5 to 8 inches for winter protection. On

<sup>1</sup>Identified by Range Botanist V. L. Cory of the Sonora, Texas, Substation. Mr. Cory reports that the species "flowers and sets fruit quite abundantly but so far as we know never produces viable seed." He suspects it may prove to be "a lethal mutation of *O. lindheimeri* Englm.," the predominant cactus of the Rio Grande Plains.

<sup>2</sup>Range research work is conducted here by the Northern Rocky Mountain Forest and Range Experiment Station of the Forest Service in cooperation with the Bureau of Animal Industry and the Montana Agricultural Experiment Station.



November 26, 1934, it was noted that many of the exposed cactus internodes were frozen hard and had a thin coating of ice, while straw-covered internodes were pliable. The lowest temperature between November 2 and 26 was  $21^{\circ}$ , which was preceded by four days with minimum temperatures ranging from  $22^{\circ}$  to  $29^{\circ}$ . All uncovered cactus plants were apparently damaged or killed by this period of frosty weather.

Two or three of these spineless cactus slabs were potted and taken inside a residence during the winter. These were still thriving during the summer of 1937.

In late April 1935, all plants in this field, both exposed and covered, were found to be reduced to a soft lifeless mass of greenish gray pulp. It is apparent that this spineless cactus from Texas cannot survive eastern Montana winters where temperatures down to minus 30 and 40 degrees occasionally occur. Unless a more cold-resistant variety is developed to withstand such temperatures, Montana will be unable to benefit from the remarkable productiveness as reported from Texas of this source of emergency range forage.—LEON C. HURTT, *Northern Rocky Mountain Forest and Range Experiment Station, U. S. Forest Service, Missoula, Montana.*



### A LABORATORY FOR SEDIMENTATION STUDIES

A LABORATORY designed to test the sediment-load of streams has been built by the Works Progress Administration of North Carolina across Rocky Creek in Iredell County for the Dept. of Agriculture. Sedimentation studies will be the aim of the Soil Conservation Service work at this station.

Spanning the stream, 14 concrete veins spaced 5 feet wide adjoin concrete and stone revetments. Four feet below each section is a 16-inch pipe, leading to a pump house. Hydraulic oil cylinders permit a sample of each or any vein to be pumped into the vats.



FIG. 1.—Construction for sedimentation studies on Rocky Creek in Iredell County, North Carolina

Qualitative and quantitative analysis of the samples will be made to determine from the suspended load what bed load of sediment is carried by the stream under all conditions.

North Carolina, immense developer of water power, has a vital interest in the experimentations which aim to find out how to prevent depletion of reservoir capacity; to determine the life of a reservoir by finding out exactly what went into it after each rain; the relationship between the sediment load and hydraulic functions of a stream; how much damage is being done to land on a particular watershed and how much would be justifiable to spend in a particular section to control soil erosion and the best method to adopt for that purpose; conservation of navigability of streams; and the prevention of flood damage.

Similar devices are being installed at Greenville, South Carolina, and Dadeville, Alabama.

## AGRONOMIC AFFAIRS

### STUDENT SECTION ESSAY CONTEST

THE American Society of Agronomy will again sponsor a Student Essay Contest. The Chicago Board of Trade has donated considerable financial assistance to make it possible to grant rather large rewards for outstanding papers. Students presenting the best papers will receive awards as follows:

The first three winners will receive expense money to enable them to attend the International Grain and Hay Show in Chicago, the total allotment for the three not exceeding \$150.00. The amounts granted will vary with the distance the winners are from Chicago. For example, if a Wisconsin student won first and an Oregon student second, it would be desirable to grant a larger amount to the Oregon student as his expenses would be greater. The committee reserves the right to adjust this as conditions warrant. In addition, the three high men shall receive appropriate medals and a year's subscription to the JOURNAL of the American Society of Agronomy. The winners of the fourth, fifth, sixth, and seventh places will receive cash awards of \$20, \$15, \$10, and \$5, respectively.

All essays must be prepared by undergraduate students. Students graduating during the course of the 1937-38 school year or those graduating during the summer school of 1938 are eligible, providing their papers are submitted before graduation. A certification of eligibility to qualify as an undergraduate, signed by the dean of the college, must accompany each paper.

Papers should be typed, double spaced, and should not exceed 3,500 words in length, *An abstract of not more than 500 words must accompany each paper.* Abstracts should be prepared carefully as it is planned to publish the best. Failure to submit an abstract will disqualify the paper.

The title for the essay shall be "Contributions of Agronomic Research to Agricultural Progress."

It is suggested that students may choose to develop the subject either from the viewpoint of crops or soils, or of both, and may draw upon those fields for specific examples.

The committee suggest that where several papers are entered from a given institution, the local representative of the Society review the essays and submit only the best articles. This will save work for the committee and reduce mailing expenses.

Essays must be in the hands of the Chairman of the committee, H. K. Wilson, University Farm, St. Paul, Minnesota, not later than October 1, 1938.

**SPECIAL MEETING OF SECTION V, SOIL SCIENCE  
SOCIETY OF AMERICA**

A SPECIAL meeting of Section V of the Soil Science Society of America was held at Knoxville, Tenn., April 8 and 9 primarily for the purpose of a conference of Soil Survey field men working in the various counties in the Tennessee Valley area. All persons interested in soils and agricultural work in general were invited to participate in the discussions.

Three general sessions were held with Messrs. W. E. Hearn, S. S. Obenshain, and L. R. Schoenmann acting as chairmen and with a number of papers on a wide variety of topics. W. M. Landess opened the conference with an address on "Happy Lands" and Dr. C. E. Kellogg discussed "The Relationship of Scientific Classification of Soils to Problems of Applied Soil Science". The second afternoon was devoted to a session for federal and state administrative officials and a special period for a discussion of field problems by field men in attendance with W. E. Hearn presiding.

The meeting was brought to a close with a banquet on the evening of April 9 with Prof. T. B. Hutcheson of Virginia Polytechnic Institute as toastmaster and the Hon. H. L. Brown, Assistant Secretary of Agriculture, as guest speaker.

**SUMMER MEETING OF SOUTHERN SECTION OF SOCIETY**

THE summer meeting of the Southern Section of the Society will be held in Alabama from August 8 to 12, under the auspices of the Agronomy and Soils Department of the Alabama Polytechnic Institute. An automobile tour through the state has been arranged for the purpose of visiting substations and experiment fields and the station at Auburn. Southern agronomists and agronomists outside the southern area are especially invited to participate. For further details, communicate with Dr. J. W. Tidmore, Department of Agronomy and Soils, Alabama Polytechnic Institute, Auburn, Ala.

**NEWS ITEMS**

DR. J. W. TURRENTINE, President of the American Potash Institute, Inc., Washington, D. C., has been awarded the gold medal of the Academie d'Agriculture de France for the collaboration of the Institute in the preparation of the book on "Potash Deficiency Symptoms" recently published in Berlin.

A MEETING of the Alfalfa Improvement Conference will be held at Manhattan, Kansas, June 24 and 25, immediately following the meeting of the Corn Belt Section of the American Society of Agronomy in Missouri.

# JOURNAL OF THE American Society of Agronomy

VOL. 30

MAY, 1938

No. 5

## LOSSES OF PHOSPHATE FROM A LIGHT-TEXTURED SOIL IN ALABAMA AND ITS RELATION TO SOME ASPECTS OF SOIL CONSERVATION<sup>1</sup>

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THE problem of supplying crops with phosphate is very important because most soils, especially those of the humid South, are deficient in available phosphate. Furthermore, phosphates added in fertilizers are soon made unavailable by being fixed into insoluble forms by components in the colloidal fraction of the soil (5),<sup>3</sup> and it is generally believed that these fixed phosphates accumulate in the soil profile.

Several investigators (2, 3, 4, 6, 7, 8) have reported that slight amounts of phosphates have moved into the lower layers of the soil, but they believed this movement to be chiefly mechanical. Obviously, the greatest residual accumulation should then be in the upper soil layers. Undoubtedly, this accumulation should be of considerable extent in heavily phosphated fields in climates where winter erosion is slight, or where the vegetative cover is heavy throughout the year; but in the light-textured, clean-cultivated soils of the humid South, where erosion is great throughout the year, the accumulation is likely hindered. Where erosion removes the topsoil to plow depth every few years there can be no accumulation of phosphate. Where the land lies nearly flat, erosion does not remove a great volume of soil, and only muddy water, colloidal suspension, runs along the furrows in the middles and away. Since this type of erosion does not deface the appearance of the field, it is generally not considered extremely important to the farmer. Almost no data exist to indicate what the phosphate losses are in the small amount of colloidal material that is lost from soils that are considered not to be seriously eroded.

An opportunity to study the movement of residual phosphate in a loamy sand (Norfolk) that had received various kinds and amounts

<sup>1</sup>Contribution from the Department of Agronomy and Soils, Alabama Agricultural Experiment Station, Auburn, Ala. Published with the approval of Director. Received for publication January 26, 1938.

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<sup>3</sup>Reference by numbers in parenthesis is to "Literature Cited," p. 374.

of phosphate fertilizers and on which crop yield records had been obtained for a period of 26 years existed in the Cullars rotation experiment on the Alabama Experiment Station farm at Auburn, Alabama.

The object of this paper is to report the results of a study of the phosphate situation in the soils of this experiment and to interpret the significance of these results as they relate to the problem of maintaining an adequate supply of available phosphate in soils and to the conservation of soils.

### DESCRIPTION OF CULLARS ROTATION EXPERIMENT

This field experiment was started in 1911 by M. J. Funchess on a Norfolk loamy sand and has for its purpose the studying of the effects of legumes as soil improvement crops in a 3-year rotation of cotton, corn, and oats. The test contained three tiers, each with 14 1/20-acre plats, but only a few of these are involved in the study reported here. A more detailed description of the experiment is published elsewhere (1, 9).

The fertilizer treatments on the plats studied, the total amount of  $P_2O_5$  added in the 26-year period, and the average annual yields of the three crops as shown in Table 1. The rate of application of the phosphates was not uniform throughout the period; therefore, only the total amount of  $P_2O_5$  added is given. This figure was obtained by assigning the total  $P_2O_5$  content of superphosphate at 18% and that of the rock phosphate at 32%. The yield data will be discussed later when other factors are presented.

### METHOD OF SAMPLING AND MECHANICAL COMPOSITION OF SOIL

Since the phosphate fertilizers were added in narrow strips in the row, it was necessary to composite the topsoil samples by taking a cross-section of the soil across the rows and middles. This was done by taking 8- by 1-inch cores every 6 inches across the entire plat on each tier. Each composite sample contained 180 such cores. The subsoil samples were taken from the row at consecutive 8-inch depths to 56 inches and each sample for any horizon was composited from three locations on corresponding plats from each of the three tiers.

The mechanical composition was determined on each sample and since the soils showed a fair uniformity, the data are presented from one plat only, *vis.*, plat 5. The clay content of the soil and a diagrammatic interpretation of the data with regard to the movement of the clay fraction away from or into the soil column is given in Fig. 1. Since data are not available on what the clay content of this soil would have been without any movement of the clay, the results cannot be accurately analyzed; however, some assumptions seem obvious. Horizon 1 (0-8 inches) contains less clay than any other horizon. If this horizon had lost its clay into the subsoil at the rate at which it moved down from horizons 2, 3, and 4, the clay content would have been 9% instead of 6%. Apparently, the rate of loss from horizon 1 was greater than that from horizons 2, 3, and 4, and this loss can be attributed to erosion. The amount of soil lost by erosion is represented by "A" and is equal to about 3% of the whole soil, which is 33.3% of the clay fraction. Data on the loss of phosphate in the eroded clay fraction will be presented later to substantiate this interpretation.

TABLE 1.—Results obtained on the plats of the *Cullers rotation experiment studied*.\*

Plat No.	Kind of fertilizers used	Total amount of $P_2O_5$ added in the 26-year period, lbs. per acre	Av. annual crop yields per acre, 1911-1936, inclusive			$P_2O_5$ removed by crops in 26 years, lbs. per acre†
			Cotton, lbs. seed cotton	Corn, bu.	Oats, bu.	
2	Nitrate of soda, 240 lbs. per acre annually (Kainit and dried blood, 1911-24).....	0	723	35.6	35.0	258
3	Superphosphate, 1911-32, none since; nitrate of soda, 240 lbs. per acre, annually (Kainit and dried blood, 1911-24).....	1,123	1,239	49.8	48.4	369
4	No fertilizers.....	0	367	24.6	12.4	132
5	Rock phosphate, 1911-32, none since; nitrate of soda, 240 lbs. per acre, annually (Kainit and dried blood, 1911-24).....	3,994	1,195	47.2	50.4	366
8	Superphosphate, 1911 to present; muriate of potash, 50 lbs. per acre, annually (Kainit, cottonseed meal, 1911-24).....	715	939	35.4	24.7	234
9	Rock phosphate, 1911-32, superphosphate 1933 to present; muriate of potash, 50 lbs. per acre, annually (Kainit, cottonseed meal, 1911-1924).....	2,371	862	36.1	27.3	241
10	Same as plat 9.....	2,371	647	30.7	23.5	201

\*Rotations used: Previous to 1932, cotton—oats, cowpeas, vetch—corn interplanted with cowpeas, vetch. Since 1932, cotton, vetch—corn interplanted with summer legumes—oats, summer legumes.

†These values were obtained by using the following compositions of  $P_2O_5$  in percentage for the harvested crops:

Seed cotton, 0.588. Corn on cob, 0.526. Weight grain oats  $\times 2.5$  = weight sheaf oats.

Grain oats, 0.755. Corn in husks, 0.465. Weight shelled corn  $\times 1.3$  = weight corn in husks.

Oat straw, 0.298. Corn husks, 0.252.

The plats have a uniform slope of about 0.8% and thus the area is generally considered to have lost no soil by erosion. Also, the elevation of the permanent plat stakes with respect to the soil indicates that little or no coarse soil material has been lost that would appreciably lower the elevation of the soil. Data in this paper indicate, however, that erosion of the fine soil fractions has been considerable and is very significant in relation to the loss of plant nutrients as exemplified especially by the losses of phosphates.

Horizons 4 and 5 contain 18% clay. Since these two layers contain the same amount of clay, they are taken to represent the transition between the horizons of eluviation and illuviation. This is assuming that the rate of movement into these horizons was equal to the rate of movement out, in which case 18% represents the amount of residual clay in the soil, i.e., the clay formed *in situ*. Evidently, the clay has accumulated in horizons 6 and 7 and below the 56-inch depth.

#### PRESENT PHOSPHATE CONTENT OF THE SURFACE SOILS

The total amount of phosphorus in the soils of the various plats and the solubility of the phosphate at different pH values were determined and the results are shown in Table 2. These data show several facts that are not directly pertinent to the theme of this paper, but are worthy of mention in relationship to the behavior of phosphates.

TABLE 2.—*The total phosphorus content in the surface 8 inches of soil and the amount of phosphate soluble in water at various pH levels in the plats of the collars rotation experiment on Norfolk loamy sand.*

Plat No.	pH	P <sub>2</sub> O <sub>5</sub> soluble at various pH levels, lbs. per acre				Total P <sub>2</sub> O <sub>5</sub> by fusion, lbs. per acre 8-inch depth
		pH of soil 1-2, soil-water suspension		pH 3.0, 1-200, 0.002N H <sub>2</sub> SO <sub>4</sub>	pH 2.0, 1-200, KH <sub>2</sub> SO <sub>4</sub>	
		Inorganic	Organic			
B*	6.1	0.0	0.3	49	46	312
2	5.4	0.3	0.0	40	50	365
3	5.5	0.9	1.0	50	201	408
4	5.3	0.3	0.0	26	186	269
5	5.4	0.9	0.6	165	372	659
8	5.4	0.0	1.2	130	138	371
9	5.4	1.3	1.6	293	459	812
10	5.4	1.5	1.4	175	459	824

\*Soil taken from the hedge fence row at the edge of the plats and represents a soil that has lost no phosphate by erosion or by removal in harvested crops. The phosphate content of this soil is assumed to be similar to that of the soils in the plats before the experiment was started.

\*Kainit and dried blood, 1911-1924.

It will be noted that the amount of phosphate entering solution increased generally with the increase in the acidity of the solvent. The amount soluble in water was extremely low, even in the soils that had been heavily phosphated. (See plats 3, 5, 8, 9, and 10 in Table 1). These plats contained the greatest amount of water-soluble organic phosphate. Plats 2 and 4 had received no phosphate fertilizers and contained no water-soluble organic phosphate. The phosphate soluble at pH 3.0 (Truog's method) compared only roughly with the crop yields and with the total phosphates in the soil. The same relation was



true of the phosphates soluble at pH 2.0, except that the amount soluble was usually greater than that at pH 3.0.

The total phosphorus content, obtained by the fusion method on duplicate samples showed a generally low amount of phosphorus in all of the soils. This seems unusual since, for example, plat 2, with no phosphate fertilization, had 365 pounds of  $P_2O_5$  per acre in 8 inches of its surface soil; whereas, plat 5, with 3,994 pounds per acre of  $P_2O_5$  added in rock phosphate over a period of 22 years (none added since 1932) had only 659 pounds of  $P_2O_5$  in the topsoil. If the phosphorus content of soil B in Table 2 is accepted as being similar to that of the plat at the start of the experiment, 312 pounds of  $P_2O_5$ , the phosphate in the soil of plat 5 at the beginning of the test, subtracted from the 659 pounds of  $P_2O_5$  leaves 347 pounds of  $P_2O_5$  as the accumulated residue. This leaves 3,647 pounds of  $P_2O_5$  to be accounted for. Subtracting 366 pounds for the  $P_2O_5$  removed from this plat in the harvested crops in the 26-year period (Table 1), 3,281 pounds of  $P_2O_5$  remained to be accounted for as having moved into the subsoil, or as having been lost by erosion.

#### DISTRIBUTION OF PHOSPHATE IN THE SOIL PROFILE

Since there was only a relatively small amount of total phosphate accumulated in the surface horizons of the phosphated plats, the subsoil horizons of some plats were analyzed to determine if any appreciable amount of the phosphate had moved into the lower horizons. The data of these analyses are given in Table 3. In this table the total phosphate content of the various horizons of the three cropped plats which had received (a) no fertilizer, plat 4; (b) nitrogen only, plat 2; and (c) phosphate plus nitrogen, plat 5, were compared with the total phosphate content of corresponding horizons of the uncropped soil, soil B.

It will be noted that the soil horizons below 8 inches on the phosphated plat, plat 5, had 170 pounds less total  $P_2O_5$  than the same horizons in soil B, which is the check soil in this study representing the composition of the soils in the plats at the start of the experiment. This is evidence that the movement of phosphates into the subsoil was too insignificant to account for any appreciable residual amount of accumulation. From these results the conclusion was made that the phosphate unaccounted for must have been lost in the clays of the muddy waters that have moved off the land in heavy rains. Other evidence to substantiate this conclusion is presented later.

Table 3 shows other facts that are of interest. Plat 2, receiving only a nitrogen fertilizer, produced larger crop yields and gave up more phosphate in its harvested crops than plat 4 which was unfertilized (Table 1). Yet the results (Table 3) show that plat 2 contained 53 pounds more  $P_2O_5$  at the end of 26 years of cropping than it had at the start and that plat 4 had 43 pounds less  $P_2O_5$  in its surface soil than at the start. To find that the larger crop yields had produced the richer surface soil seemed like an unreasonable situation; however, a study of the composition of the subsoils in the two plats shows that the horizons below 8 inches in plat 2 had lost 166 pounds more  $P_2O_5$



than these horizons in plat 4. This indicates that more phosphate had been "pumped" to the surface soil in plat 2 than in plat 4 by the growing plants, thereby causing an enrichment of phosphate in the topsoil on the nitrated plat from the crop residues at the expense of the subsoil. The explanation for this difference is presented in connection with the study of the root systems of corn on these plats.

TABLE 3.—*The total  $P_2O_5$  content in the different horizons of a loamy sand from variously treated plats compared to that in the horizons of the same soil uncropped and unfertilized for a 26-year period with a 3-year rotation of cotton, corn, and oats.*

Depth of soil horizons, inches	Original soil, (soil B), no fertilizers, no erosion, and no crops removed, lbs. total $P_2O_5$ per acre	Plat 2, 240 lbs. nitrate of soda annually since 1924 and cropped for 26 years*		Plat 4, no fertilizers; cropped for 26 years		Plat 5, 3,994 lbs. of total $P_2O_5$ in 22 years as rock phosphate, no phosphate last 4 years, plus 240 lbs. nitrate of soda annually since 1924, cropped for 26 years*	
		Lbs. total $P_2O_5$	Total $P_2O_5$ content compared with that of Soil B	Lbs. total $P_2O_5$	Total $P_2O_5$ content compared with that of soil B	Lbs. total $P_2O_5$	Total $P_2O_5$ content compared with that of soil B
Surface soil: 0-8	312	365	+53	269	-43	659	+347
Subsoil: 8-16	545	346	-199	350	-195	467	-78
16-24	336	418	+82	330	-6	386	+50
24-32	373	308	-65	337	-36	427	+54
32-40	435	266	-169	371	-64	343	-92
40-48	450	266	-184	321	-129	384	-66
48-56	545	462	-83	523	-22	507	-38
Sum of all horizons	2,996	2,431		2,501		3,173	
Loss of total $P_2O_5$ in horizons below 8 inches			-618		-452		-170

\*Kainit and dried blood for the first 14 years.

In comparing the losses of phosphate from the subsoils of plats 2, 4, and 5, it is interesting to note that the loss was 618, 452, and 170 pounds of  $P_2O_5$ , respectively. Plat 2 with only a nitrogen fertilizer (nitrate of soda) made surprisingly good yields and contributed 258 pounds of  $P_2O_5$  to the harvested crops. It is obvious that here the crops drew much of this phosphate from the lower horizons. The

residual phosphate enrichment in the surface soil and impoverishment in the subsoil substantiates this fact. Plat 4, with no fertilizers, made the lowest yields and lost only 132 pounds of  $P_2O_5$  in the harvested crops. Undoubtedly, these crops also pulled some phosphate from the subsoil. Plat 5, with phosphate and nitrogen fertilizers, produced larger yields than plats 2 and 4 and lost 366 pounds in its harvested crops. Here the subsoil horizons were only 170 pounds of  $P_2O_5$  short of their original content. Since the behavior on plat 2 indicates that much phosphate has been carried upward by the plant roots of the vigorous plants, the crops on plat 5 with strong plants probably also carried much phosphate upward. Therefore, the 170 pounds loss from the subsoil is likely a value diminished by slight eluviation of clay-fixed phosphate into the subsoil from the phosphated surface soil.

#### DISTRIBUTION OF PHOSPHATE IN THE SOIL FRACTIONS

In an attempt to learn more about the losses of the residual phosphate, soils from plats 4, 5, and 9 were fractionated into three group sizes of particles and analyzed for the total phosphate content of each. The clay fraction represented material that remained in suspension in the upper 6 inches of a water suspension for 16 hours. The silt fraction was made up of the material that did not settle below the 6-inch depth in 15 minutes but that did settle below that depth in 16 hours. The sand fractions contained the particles that settled below 8 inches in 15 minutes. The fractionation of the silt and sands was repeated several times to separate out the included particles that were not wanted in any of the particular fractions. Some soil material was lost by this washing process; therefore, the sum of the phosphate contents of the three fractions does not exactly equal the total amount found in the whole soil. The soil samples for these fractions were composites from the plats in the middle tier of the experiment only. The total phosphate contents of the different soil fractions are given in Table 4. It is interesting to note that the phosphate content of the clay fractions is much higher than that in the coarser fractions. This fact is most pronounced for plats 5 and 9 which had received phosphate fertilizers. Here, over 50% of the total phosphate in the whole soil is contained in the fine fraction which is only 6% of the total soil. This situation is very significant for it shows how important the clay fraction of a soil really is in its relation to the conservation of phosphates.

The total phosphate content of the surface 8 inches of plat 4, which had received no fertilizers, was only 269 pounds of  $P_2O_5$  per acre. The fractionation data show that this total phosphate content was highest in the clay fraction, but it did not differ greatly in the distribution on the whole soil basis. This fact indicates that the phosphates in this soil are mineral phosphates associated with the internal structures of the soil minerals, whereas the phosphates of the clay fractions of the phosphated plats include also precipitated and surface-absorbed phosphates.

TABLE 4.—*The distribution of  $P_2O_5$  in the various fractions of the surface 8 inches of a Norfolk loamy sand fertilized for 26 years with different fertilizers.*

Kind of soil fractions	Sands	Silt	Clay
Amount of fraction in soil, % . . . . .	74	20	6
Weight of fraction per acre 8-in. depth, lbs. . . . .	1,998,000	529,000	173,000
Plat 4, no fertilizers:			
Total $P_2O_5$ in fractions, by analyses, p.p.m. . . . .	52	162	482
Total $P_2O_5$ in fractions, per acre of soil, lbs. . . . .	103	86	74
Distribution of total $P_2O_5$ in fractions, % . . . . .	39.2	32.6	28.1
Plat 5, rock phosphate 22 years; no phosphate last 4 years:			
Total $P_2O_5$ in fractions, by analyses, p.p.m. . . . .	69	224	1976
Total $P_2O_5$ in fractions, per acre of soil, lbs. . . . .	138	118	341
Distribution of total $P_2O_5$ in fractions, % . . . . .	23.1	19.7	57.1
Plat 9, rock phosphate 22 years, superphosphate last 4 years:			
Total $P_2O_5$ in fractions, by analyses, p.p.m. . . . .	78	286	1,936
Total $P_2O_5$ in fractions, per acre of soil, lbs. . . . .	156	152	335
Distribution of total $P_2O_5$ in fractions, % . . . . .	24.3	23.6	52.0

## PHOSPHATE LOST BY EROSION

The various data on the phosphate losses and accumulations are brought together in Table 5 to form a balance sheet for the plats studied. These data show that only about 32% of the  $P_2O_5$  added in the superphosphate and 9% of the  $P_2O_5$  added in the rock phosphate was used by the crops in producing harvested products. Since the accumulation of residual phosphate was extremely small and since only an insignificant amount had moved into the subsoil, as shown in other data of this study, the great loss of phosphate from these plats must be attributed to erosion losses. Thus about 60% of all the  $P_2O_5$  from the superphosphate and 82% of the  $P_2O_5$  from rock phosphate has been washed away from these plats in the 26 years of their duration.

No data are available on the amount of clay material lost by erosion from these plats. The data in Fig. 1 suggests that 3% of the topsoil horizon has been lost by erosion and that this loss was only from the clay fraction. Since the topsoil contained only 6% clay, the loss of 3% of the soil as clay represents about a 33% loss of the clay fraction. Undoubtedly, some of this loss occurred before the beginning of this test. Nevertheless, the data in Table 4 show that if only a slight clay loss had occurred, there would still be a great loss of phosphate, since the phosphate is largely contained in the clay fraction. This seems to be especially true of phosphates fixed in the soil from fertilizers.

To obtain additional data on the phosphate losses from these plats some of the muddy water runoff was collected and analyzed. Three 4-gallon cans were placed on plats 4, 5, and 9, between the rows in such a way that the runoff would be saved. These cans were installed in September 1937 and 2.14 inches of rain fell in small showers before

TABLE 5.—A balance sheet of the phosphate losses and accumulations in a 26-year period in the top 8 inches of Norfolk loamy sand in plots variously fertilized.

	Fertilizer treatment					
	Plat 2, nitrogen only since 1924	Plat 3, super- phosphate for 22 years, no phos- phate last 4 years, + nitrogen	Plat 4, no ferti- lizer	Plat 5, rock phos- phate for 22 years, no phos- phate last 4 years, + nitrogen	Plat 8, super- phosphate entire period 26 years + potash	Plat 9, rock phos- phate for 22 years, super- phosphate last 4 years + potash
						Same as plat 9
P <sub>2</sub> O <sub>5</sub> in first 8 inches soil at start of test, lbs.	312	312	312	312	312	312
P <sub>2</sub> O <sub>5</sub> in first 8 inches soil after 26 years cropping, lbs.	365	408	269	659	812	824
Gain or loss in the 26 years cropping, lbs.	+53	+86	-43	+347	+59	+512
P <sub>2</sub> O <sub>5</sub> added in 26 years, lbs.	0	1,123	0	3,994	715	2,371
P <sub>2</sub> O <sub>5</sub> removed by crops in 26 years, lbs.	258	369	132	306	234	201
Percentage of P <sub>2</sub> O <sub>5</sub> added used by crops.	—	32.8	—	9.1	32.6	8.5
P <sub>2</sub> O <sub>5</sub> supplied from subsoil, assuming no erosion, lbs.	311	668	89	?	?	?
P <sub>2</sub> O <sub>5</sub> lost by erosion, lbs.	307†	60	363†	3,281	422	1,658
Percentage of added P <sub>2</sub> O <sub>5</sub> lost by erosion.	—	—	—	82	59	70

\*These values obtained from soil B (Table 2) taken from the hedge row at the edge of the plats.

†The data in Table 3 indicate that when the phosphate lost is

and 4, respectively. Accordingly, then, the loss of  $P_2O_5$  by erosive

from the subsoil when assuming no erosion, or 307 and 303 pounds

Figure 1. The effect of the number of trials on the number of correct responses. The number of correct responses was significantly higher than the number of incorrect responses for all groups. The number of correct responses was significantly higher than the number of incorrect responses for all groups. The number of correct responses was significantly higher than the number of incorrect responses for all groups.

*(continued)*

\*These values obtained from soil B (Table 2) taken from the hedge row at the edge of the plats.

†The data in Table 3 indicate that when the phosphate lost by erosion is included, the amount of  $P_2O_5$  drawn out of the subsoil was 618 lbs. and 452 lbs. for plots 2 and 4, respectively. Accordingly, then, the loss of  $P_2O_5$  by erosion on plots 2 and 4 was the difference between these values and the values given for the  $P_2O_5$  supplied from the subsoil when assuming no erosion, or 307 and 363 pounds, respectively.

any runoff occurred. A 2.92-inch rainfall occurred 21 days later and the cans filled with runoff water containing about 0.3% of suspension.

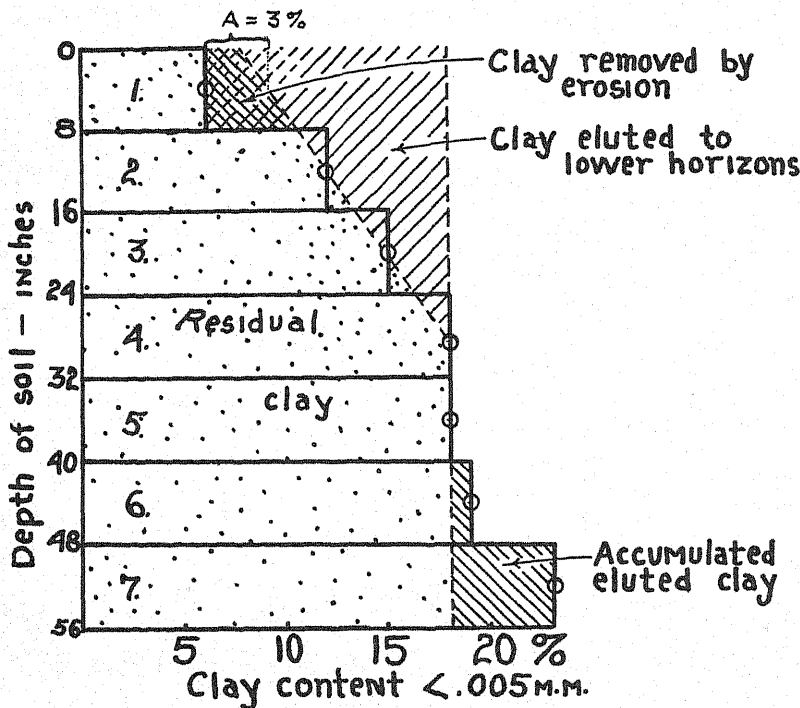


FIG. 1.—Clay content by 8-inch layers of the Norfolk loamy sand from the Cullars rotation experiment and a diagrammatic interpretation of the data with regard to the clay that has been lost out of the top soil by erosion, the clay washed out of the upper horizons into the lower subsoil, and the clay accumulated in the lower horizons.

The suspended material in the runoff from plats 4, 5, and 9 contained 660, 687, and 917 p. p. m. of  $P_2O_5$ , respectively. These figures are high considering that the data from these plats show that the phosphates have already been lost to the point where the total  $P_2O_5$  content is low. These data also show the manner in which the phosphate losses occur.

The phosphate content in the runoff fraction is not as high on plats 5 and 9 as that of the laboratory separated fraction reported in Table 4. The laboratory samples were taken from the entire 8-inch depth of the surface soil, and thus contained material not exposed to the surface of the land and the dispersing and washing effects of the season's rains; whereas, the runoff samples were composed of material lying on the surface of the land that had been rain washed throughout the summer thereby removing phosphate-bearing clays and causing a lowering of the phosphate content of the top material.

## EFFECT OF A NITROGEN FERTILIZER ON THE USE AND CONSERVATION OF PHOSPHATE

The data in Table 6 from plats 2 and 4 where nitrogen and potassium fertilizers and no fertilizers, respectively, were used, show a relationship to the use and conservation of phosphates that helps to explain why an average annual yield of corn and oats of 35 bushels per acre each was possible without the use of a phosphate fertilizer. It has been referred to before that the phosphate content of plat 2 was higher by 53 pounds of  $P_2O_5$  at the end of the 26 years of cropping than at the start of the experiment. The explanation for this seems to be associated with the fact that the nitrogen fertilizer had stimulated the root development to such an extent that more phosphate was used from the subsoil on plat 2 than on plat 4 where the roots were not nearly so well developed.

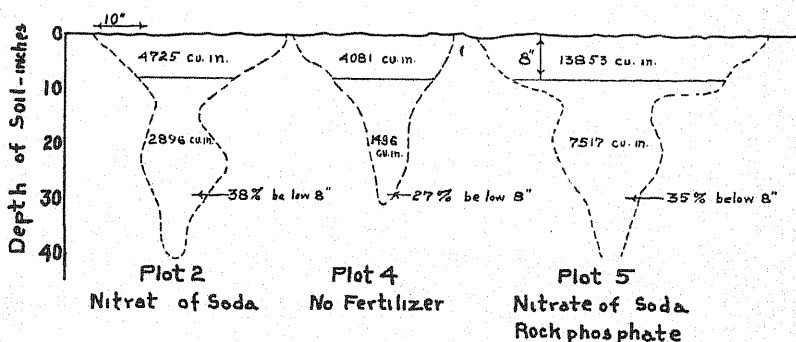


FIG. 2.—Outline of distribution of the root systems of corn on a loamy sand, showing the effect of nitrogen and phosphate fertilizers in stimulating the root growth and the penetration of the roots into the soil below the 8-inch depth.

Fig. 2 shows the outline of the distribution of corn roots on plats 2, 4, and 5. These diagrams were obtained by examining the root distribution from the walls of pits dug beside the stalks. The numbers of small fibrous roots were much more pronounced on plats 2 and 5 than for plat 4. The gross volume for the root spread in the subsoil below the 8-inch horizon was twice as great in the nitrated plat as in the non-fertilized plat. Undoubtedly, the larger phosphate content of the surface soil of plat 2 was caused by the larger plant residues left on the field by the larger crops.

## DISCUSSION

The data presented show that the accumulation of phosphate in a clean-cultivated light-textured soil in a humid climate with open winters is not nearly as great as is commonly believed. Since phosphates are not leached as nitrates and potash fertilizers are, the prevailing concept has been that the phosphates are accumulating, especially in fields where erosion is not defacing the land. The data show,

TABLE 6.—*The crop yields and phosphate balance in a loamy sand from a plat receiving no fertilizer and a plat fertilized with nitrogen only.*

Plat No.	2	4
Fertilizer treatment	240 lbs. per acre of ni- trate of soda*	No fertilizers
Average annual crop yields for 26 years:		
Cotton, lbs. seed cotton per acre.....	723	367
Corn, bu. per acre.....	35.6	24.6
Oats, bu. per acre.....	35.0	12.4
P <sub>2</sub> O <sub>5</sub> in acre 8-inch depth:		
At start, lbs.....	312	312
At end, lbs.....	365	269
P <sub>2</sub> O <sub>5</sub> gained or lost in 26 years, lbs.....	+53	-43
P <sub>2</sub> O <sub>5</sub> removed by crops in 26 years, lbs.....	258	132
P <sub>2</sub> O <sub>5</sub> brought out of subsoil in 26 years, lbs.....	305	89
Soil-root volume, 0-8 inches, cu. in.....	4,725	4,081
Soil-root volume below 8 inches, cu. in.....	2,896	1,496

\*Kainit and dried blood for the first 14 years.

however, that the phosphate losses are very large even if the land shows no apparent mass or accelerated erosion, because whatever the amount of the muddy water that runs off the land, it carries off heavy loads of phosphates that are associated with the clay fraction of the soil. When it is considered that phosphate is usually the highest percentage ingredient in most of the common mixed fertilizers and only 9 to 32% of this ingredient is used by the crops in making harvestable products, the economic loss becomes very great when the unused portion is permitted to be washed away. If the clay runoff were stopped, the phosphates would accumulate and eventually the stress for phosphate would be relieved. The accumulation of phosphate is important even if the phosphates are fixed into relatively insoluble forms. A solubility of 0.01% would yield 10 pounds of available phosphate from a residue of 1,000 pounds of P<sub>2</sub>O<sub>5</sub>, which might be enough for the plants; yet, the same solubility for a lower residual amount of phosphate would be inadequate. This illustration is borne out in a pasture fertilization experiment in the Black Belt of Alabama where 200 pounds of 16% superphosphate per acre in an annual application is sufficient for good plant growth after several years, but was not sufficient at the start. On these soils approximately a 400-pound rate of this fertilizer is required for the cultivated crops where erosion losses are greater. On a sandy loam soil (Hartsells) at the Sand Mountain Substation an experiment on the residual effect of phosphate showed that 90 pounds of P<sub>2</sub>O<sub>5</sub>, applied annually for a period of 5 years, did not result in a phosphate carry-over sufficient to maintain the cotton yields for 2 years. In view of the present data, this suggests a great erosion loss as well as a loss by fixation.

This paper has dealt with phosphate losses as only one factor in the maintenance of productive soils. The significance of these results reach

beyond this one factor for in the conservation of phosphates other important elements as potassium, calcium, and magnesium, and minor elements are also conserved. The benefit of a protective winter cover crop with roots drawing minerals from the subsoil to become incorporated into the surface soil from the plant residue cannot be overemphasized. Furthermore, if the soil is to build up its storage of plant nutrients to be revolved through the plant back to the soil, and in the bodies of micro-organisms, it is of the greatest importance that the loss of the clay fractions of the soil in muddy waters be prevented. It is also important to recognize that terraces as commonly constructed in the Southeast cannot alone adequately conserve the clay fractions that are so essential in maintaining soil fertility.

One more point about the conservation of the clay fractions to save the phosphate should be mentioned. The phosphate deposits are limited and can be exhausted (10); therefore, it is well to recognize all the factors that contribute to the efficient use of phosphate as fertilizers.

#### SUMMARY

A study was made of the residual phosphate situation in a nearly level, light-textured soil of Alabama that had been used for a 26-year period in an experiment involving a 3-year rotation of cotton, corn, and oats with various legumes and with different phosphate fertilizer treatments. The soil has been considered to be uneroded or not seriously eroded, and it has been assumed that the unused phosphates were accumulating in the soil as fixed phosphates. The data presented reveal that some of these assumptions are not correct. The principal facts are summarized as follows:

1. Where superphosphate was used for the 26-year period, 32% of the phosphate was used by the plants in making harvested products, 8% was still present as a residue, and 60% had been carried away with the clay fractions lost by erosion.
2. Where rock phosphate was used, only 9% of the total phosphate added was used by the plants and 82% was lost by erosion, the amount remaining as a residue being 9%.
3. The surface soil contained only 6% of clay, yet, in this fraction was held over 50% of the total phosphate in the soil.
4. The amount of phosphate that had moved downward in the profile was too insignificant to measure accurately; apparently, a small amount had moved down with the eluted clay.
5. The total amount of phosphate taken out of the subsoil below the 8-inch depth in 26 years by the crops on a plat receiving only a nitrogen fertilizer was 618 pounds  $P_2O_5$  per acre. Of this amount 258 pounds were removed from the field in harvested crops, 53 pounds accumulated in the surface 8 inches, and 313 pounds, or 60% lost by erosion.
6. A nitrogen fertilizer had maintained a 35-bushel corn and oat yield per acre for a 12-year period<sup>4</sup> without the use of phosphate fertilizers and had at the same time caused a slight increase in the total

<sup>4</sup>This is a 26-year period without phosphate fertilizers for kainit was used with the nitrogen the first 14 years.



phosphate content of the surface 8 inches of soil by drawing phosphate from the subsoil horizons. A plat with no fertilizers produced only 24 and 12 bushels per acre yields for corn and oats, respectively, and had depleted the surface soil by 43 pounds of  $P_2O_5$  per acre. The difference in the yields and phosphate contents of the soil is accounted for by the increased root growth in the subsoil of the nitrated soil and the greater upward movement of the phosphate from the subsoil in the more vigorous plants.

7. The data are discussed in relation to the importance of saving the clay fraction in soil conservation practices.

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## THE CYTOLOGY AND HISTOLOGY OF THE ROOT NODULES OF SOME LEGUMINOSAE<sup>1</sup>

FREDRICK WILHELM BIEBERDORF<sup>2</sup>

VARIOUS phases of nodule formation on leguminous plants have already been studied by investigators.<sup>3</sup> This paper deals with the comparative cytological and histological development of nodules of the following leguminous plants: Soybean (*Soja max* Pieper), cowpea (*Vigna sinensis* Endl.), sweet clover (*Melilotus alba* Desr.), alfalfa (*Medicago sativa* L.), vetch (*Vicia villosa* Roth.), and peanut (*Arachis hypogaea*).

### MATERIALS AND METHODS

The materials used in this investigation were obtained by growing plants in the greenhouse, in the laboratory under artificial light, and also in the field. In the greenhouse and laboratory, the plants were grown in (a) washed sand, (b) Knop's water culture in bottles, and (c) a soil consisting of one-third sand and two-thirds loam.

For early infection stages, the seeds were germinated in petri dishes between filter paper, and inoculations from agar slants were made by applying the bacteria directly to the root hairs. The bacteria used for inoculation were obtained as follows: (a) By grinding up mature nodules and making a water suspension, (b) by using soil which already contained nodule-forming bacteria, (c) by using commercial preparations of bacteria, and (d) by isolating and growing on agar slants.

The bacteria were either applied directly to the seed before planting or to the medium in which the plants were to be grown. When water cultures were used, the roots were suspended in the solution. The stems were wrapped with cotton and held erect by split stoppers. The bottles were wrapped and solution added when needed. Small crucibles with holes in the bottoms were filled with sand and partially embedded in flower pots filled with loam soil. Seeds were then planted in the crucibles. Nodules formed in the crucible, while the roots penetrated the openings in the bottoms.

An abundance of material for study was easily obtained by the above methods. Materials for study were selected at various times of the day in order to increase the possibility of obtaining cells undergoing mitosis. The killing and fixing solutions used were as follows: Flemming's weak and Bouins and chromoacetic for the younger tissue. A. F. A. solution was used for the older tissues. Other killing and fixing solutions were tried but proved less satisfactory. The paraffin method of infiltration and embedding was used for the younger tissue, but for the older and more lignified tissue, the celloidin method was employed.

Free-hand sections of fresh material were cut to make microchemical tests for starch, protein, cellulose, lignin, and gums. The embedded material was cut 8 to 20 microns in thickness. The age of the material after inoculation ranged from 12

<sup>1</sup>Also submitted to the Graduate Faculty, Iowa State College, for the degree of doctor of philosophy. Received for publication December 28, 1937.

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<sup>3</sup>For a more complete historical review see Fred, E. B., Baldwin, I. L., and McCoy, Elizabeth F. Root nodules and leguminous plants. Univ. Wis. Studies in Sci., No. 5, 1932.

hours to 11 weeks. The stains used were Delafield's haematoxylin, safranin, carbol, fuchsin with Bismark brown, and Grams iodine. The best general combination of stains used was Mayer's haem-alum and aqueous safranin. The procedure with this combination is simple and the staining is rapid as compared with some of the other stains used.

## NODULE DEVELOPMENT IN SOYBEAN

### INFECTION OF HOST TISSUE

The bacteria causing nodule formation on soybeans usually enter the host plant through the root hairs (Figs. 1, 3, 7, and 8). When the bacteria come in contact with the root hairs, a characteristic curving usually occurs (Figs. 1, 3, and 7). However, in the soybean and cowpea, infection may take place without the formation of such a curvature (Fig. 1, a). Root hairs were also found in which infection apparently took place simultaneously on opposite sides of the root hair (Fig. 1, a). From further observations it was concluded that this curvature usually takes place when infection occurs during the elongation period of the root hairs. However, if infection occurs in root hairs after elongation has ceased, this curvature will not always be exhibited.

It is apparently also possible for bacteria to enter the host plant through regular epidermal cells (Fig. 2). This was found to occur most frequently when seedlings were grown in a medium in which they obtained an abundance of moisture and produced fewer root hairs. Bacteria may also enter through breaks in the epidermis. Very little difficulty was encountered in getting infection to take place in the soybean.

Thornton (6)<sup>4</sup> found that infection coincides with the opening of the first true leaves. No such correlation was found in the soybean. It was noted that many seedlings would die or become stunted just at the stage when they were breaking through the soil before unfolding their cotyledons. This was especially found to occur when a medium was used which was highly infested with nodule-forming bacteria, such as equal parts of sand, loam, and commercial "Nitragin". Those seedlings which survived always showed a very heavy inoculation and a poorly developed root system. From all observations made, it was concluded that the stunting or death was a result of excessive infection. Thornton (7) concluded that nodule-forming bacteria are sometimes parasitic.

The bacteria begin the formation of an infection or zoogloeal strand immediately after gaining entrance to the host cell. This strand resembles a non-septate fungus hypha (Figs. 1, 2, 3, 7, and 8), and can readily be distinguished from the cytoplasm of the cell. The infection strand, in which the bacteria are embedded, has a gum-like consistency. Buchanan (1) found that nodule-forming bacteria produced large quantities of gum. It requires approximately two days from the time that the bacteria come in contact with the tip of the root hair until they have reached the inner wall of the epidermal cell, a distance

<sup>4</sup>Figures in parenthesis refer to "Literature Cited", p. 389.

of 70 to 80 microns. The number of infection strands invading the root hairs of the soybean was found to vary from one to three (Fig. 7, a).

The bacterial strand may branch or remain in a single strand while invading the root hair and basal portion of the epidermal cell (Figs. 1 and 8, a), but when the strands penetrate the cortex, branching takes place almost invariably. The branches of the infection strand ramify the cortical parenchyma (Figs. 1, 2, 3, and 8). It is from these cortical parenchyma cells that the nodule develops in the soybean. The strands in their migration often come directly in contact with the nucleus. The cells that are being invaded and those immediately surrounding them have a rather dense cytoplasm and prominent nucleus. Because of their active division, they are much smaller than the surrounding cortical parenchyma cells (Figs. 2, 7, and 9). Infection may take place at various stages of root growth. Early infection stages were found on roots which already had nodules large enough to be easily detected (Fig. 9, b). Frequently infections were noted in which the bacteria had entered through the root hair, migrated to the inner wall of the epidermal cell, but failed to penetrate deeper.

The distance which the bacteria penetrate the cortical parenchyma of the root is important in determining the exact point of the origin of the nodule. In the soybean, which has a rather thick cortical parenchyma, it was found that the infection strand penetrated only from three to five layers of the cortical parenchyma cells (Figs. 1, 7, and 9). In the radicle, the strand ordinarily penetrates to a distance about half-way between the epidermis and endodermis. In the lateral roots of the soybean, there is less cortical parenchyma and the bacteria may even penetrate the cortex to the endodermis. In no instance was it found that the bacteria had penetrated the endodermal cells. In the cortex, the bacteria appear to move towards one of the protoxylem points. However, the bacteria never reach the protoxylem since they do not pass through the endodermis or pericycle. When the bacteria have penetrated several layers of cortical parenchyma, the formation of a vascular system is initiated, forming a direct connection between one of the protoxylem points and the infected area (Figs. 9, c, 10, b, and 11, b). It appears that there is considerable transfer of material between the protoxylem and the infected area. The development of this vascular system will be described in detail later.

The infection strands within the cortex increase considerably in size. In the strands, enlargements are formed that break and liberate the bacteria (Fig. 2, a). The division of cells also breaks the infection strands, liberating the bacteria into the surrounding cytoplasm. The bacteria then multiply rapidly and fill the cells. This increase in bacterial number within the cells and products of bacterial secretion apparently cause an increased internal pressure which brings about an enlargement of the cell. Because of the frequent cell divisions of the bacteroid cells in the soybean, the infection strand is broken up into small particles and its identity completely lost (Figs. 12, a and 13, a).

Formation of the nodule begins as soon as the bacteria have invaded the sub-epidermal layer. In the soybean, the nodules originate in the third to fifth layers of cortical parenchyma cells (Fig. 9). The

epidermal cells are sloughed off, the second layer forms the epidermis of the nodule, the third layer forms the cortex of the nodule, while the fourth and fifth layers give rise to the bacteroidal tissue. During the early period of infection when the bacteria are moving toward the base of the epidermal cell, the cell enlarges greatly (Figs. 2, b, 7, a, 8, b, and 10, a). The layers below do not show such enlargement, but they are at this time beginning a very active period of cell division. The sub-epidermal cells containing bacteria are surrounded by uninfected cells during this period of active cell division. No infected cells are exposed, but they are completely surrounded by uninfected cells which are continuous with the epidermis and cortex of the root. The cortical cells containing bacteria continue to divide and enlarge, pushing outward against the epidermal layer that surrounds the infected area (Fig. 10). As the infected area increases, the cells in the outer layer also divide and expand, permitting growth to take place. In this manner, the nodule continues to grow. The young nodule does not break through the outer layers of cortical parenchyma, and it in no way resembles a lateral root in origin or development.

The soybean nodules can be detected without the aid of a hand lens within nine days after the inoculated seed has germinated (Fig. 9). At this stage, the infection strands in the soybean have almost completely lost their identity. Uninfected cells are no longer invaded by the bacteria, but the bacteroidal tissue is increased by the division of the infected cells. In the early infection stages, it was difficult to obtain material showing many mitotic figures (Fig. 2). Apparently cell division in these early stages takes place very rapidly. Attempts were made to study periodicity of the nodules. The greatest number of dividing cells were found in material selected at 10:30 a. m. on bright days (Figs. 12 and 13). Mitotic figures were also found in abundance in material selected at 1:00 p. m. and 4:30 p. m. Cell division was less frequent in materials selected at other hours. The greatest number of mitotic figures was found on days with a maximum of sunlight. The number of times an infected cell can divide could not be determined, as a large number of bacteroidal cells are formed from a comparatively small number of cells infected by the bacterial strands. The activity of the cell at first seems not to be affected by the presence of bacteria within the cell. After the cell has become well filled with bacteria, mitosis ceases. The cell, however, continues to increase in size and is often much elongated (Fig. 15). As the nodule matures, the nucleus becomes less prominent, gradually shrinks, becomes very irregular, and finally only fragments of it remain.

Scattered among the bacteroidal cells are uninfected parenchyma cells. Mitotic figures were not found in these uninfected cells after the nodule had begun to enlarge (Figs. 14, b and 15, a).

#### DEVELOPMENT OF CONDUCTIVE TISSUE

An elaborate conductive system is developed between the nodule and the xylem and phloem of the root. This conductive system becomes evident early in the nodule development. The first indication of conductive tissue formation becomes apparent when the bacteria have penetrated the first two layers of cortical parenchyma (Figs. 7,

b, 9, c, and 10, b). The first visible sign of conductive tissue formation is a division of cortical parenchyma cells between the protoxylem point and the infected area. These cortical parenchyma cells divide in such a manner that the new walls formed are almost invariably laid down parallel to the radius of the root (Figs. 9 and 10). These cells form the procambium strands which are later converted into scalariform vessels, and other conductive tissues (Figs. 17 and 18). The first conductive tissue formed is always connecting the infected area with one of the protoxylem points. Frequently conductive tissue is formed connecting the infected area with two protoxylem points (Fig. 11, b). During formation of the procambial strands, the cytoplasm is absorbed and the nucleus, much elongated, is often found lying next to one of the walls. Gradually the nucleus and remaining cell contents are also absorbed. The walls of the cells become lignified and develop into pitted tracheids and scalariform vessels (Figs. 5 and 17).

The cells surrounding the xylem are composed of parenchyma cells having a rather conspicuous nucleus and dense cytoplasm. These cells are filled with stored food, mainly starch. As the nodule continues growth, the cells surrounding the xylem continue to divide (Figs. 5 and 13, b) and increase the diameter of the vascular bundle which differentiates into xylem elements. At the region of connection between the vascular bundle of the nodule and xylem of the root, the new xylem of the bundle is in contact with the new xylem of the root. The vascular bundle becomes cone-shaped at the region where it comes in contact with the xylem of the root. The vascular bundle branches and completely surrounds the bacteroid area. The number of branches formed is not always constant, and the bundles do not come in contact with the bacteroid tissue. Several layers of cortical parenchyma are always found between the bundles and bacteroid cells (Fig. 16, c). The food, water, and other products are transported through the bundle but must diffuse through several layers of parenchyma cells before reaching the bacteria. The branches of the vascular system are also formed from procambium strands in the cortical parenchyma of the nodule (Figs. 4 and 16). More xylem and phloem cells are added to the bundles by division of cells immediately surrounding the bundles (Figs. 4, 5, and 16, b). Toward the apex of the nodule, xylem elements may not have formed as yet. The bundles have no definite arrangement except that the xylem is surrounded by parenchyma cells that are of a phloem-like nature (Figs. 5, 16, and 19). These parenchyma cells retain their meristematic power and add xylem to the bundle as the nodule increases in size (Figs. 5 and 16, a). In cross section, the branches of the vascular system often appear eccentric. In the mature nodule of the soybean, the branches of the bundle unite at the apex of the nodule. The vascular system continues to function after the nodule is fully mature and until the nodule disintegrates.

#### MERISTEMATIC ACTIVITY

Soybean nodules are spherical and from 3 to 6 mm in diameter. The shape of the nodule is determined by the various meristematic regions. The bacteroid cells divide until the nodule is 12 to 18 days

## EXPLANATION OF ILLUSTRATIONS

The drawings were made with an Abbe camera lucida and the photomicrographs with a microscope equipped with apochromatic objectives and compensating ocular.

FIG. 1.—Bacterial strands entering through root hairs and ramifying cortical parenchyma.  $\times 385$ . (a) Two infections taking place simultaneously in a single root hair. (b) Branching of bacterial strand.

FIG. 2.—Infection through a regular epidermal cell and mitotic figure in parenchyma.  $\times 385$ . (a) Break in bacterial strand liberating bacteria into cytoplasm. (b) Enlarged epidermal cell.

FIG. 3.—Two infection strands in root hair penetrating cortex.  $\times 385$ .

FIG. 4.—Early stage in the development of a branch of the vascular system of a soybean nodule.  $\times 350$ .

FIG. 5.—Later stage in the development of a branch of a vascular bundle of the soybean nodule. Note thick-walled xylem cells surrounded by phloem-like tissue.  $\times 350$ .

FIG. 6.—Apical meristem as it occurs in alfalfa, vetch, and sweet clover nodules.  $\times 350$ . (a) Apical meristem. (b) Infection strand invading newly formed cells. (c) Vascular bundle.

FIG. 7.—Three bacterial strands entering through a root hair and penetrating the cortex.  $\times 300$ .

FIG. 8.—Bacteria entering the cortex.  $\times 900$ . (a) Infection strand branching. (b) Epidermal cell.

FIG. 9.—Ten-day-old nodule and vascular system showing early stage of formation.  $\times 75$ . (a) Root hair through which infection occurred. (b) An infection that failed to develop a nodule. (c) Formation of vascular system.

FIG. 10.—A 12-day-old nodule showing the formation of the vascular system and enlargement of the infected area.  $\times 50$ . (a) Enlarged cell showing portion of root hair where infection occurred. (b) Cortical parenchyma giving rise to conductive tissue.

FIG. 11.—A 15-day-old nodule forming vascular connections with two protoxylem points.  $\times 50$ . (a) Bacteroid tissue. (b) Vascular bundle.

FIG. 12.—Portion of bacteroid area showing cell division in a 12- to 15-day-old soybean nodule.  $\times 600$ . (a) Infected cells with mitotic figures. (b) Cambial cells surrounding bacteroid tissue.

FIG. 13.—Bacteroid tissue of 15- to 18-day-old soybean nodule with mitotic figures.  $\times 600$ . (a) Infected cells with mitotic figures. (b) Cross section of vascular bundle with mitotic figures.

FIG. 14.—Bacteroid cells of soybean nodules with vacuoles. The nodule is still in enlargement stage but no mitotic figure.  $\times 600$ . (a) Vacuoles. (b) Uninfected cell.

FIG. 15.—Bacteroid cells of a mature nodule. Note how cells have elongated and vacuoles have decreased.  $\times 600$ . (a) Uninfected cell.

FIG. 16.—Nodule showing the development of the vascular system around the infected area.  $\times 600$ . (a) Longitudinal section of bundle with mitotic figure. (b) Cambial layer surrounding bacteroid tissue. (c) Cortical parenchyma. (d) Bacteroid tissue.

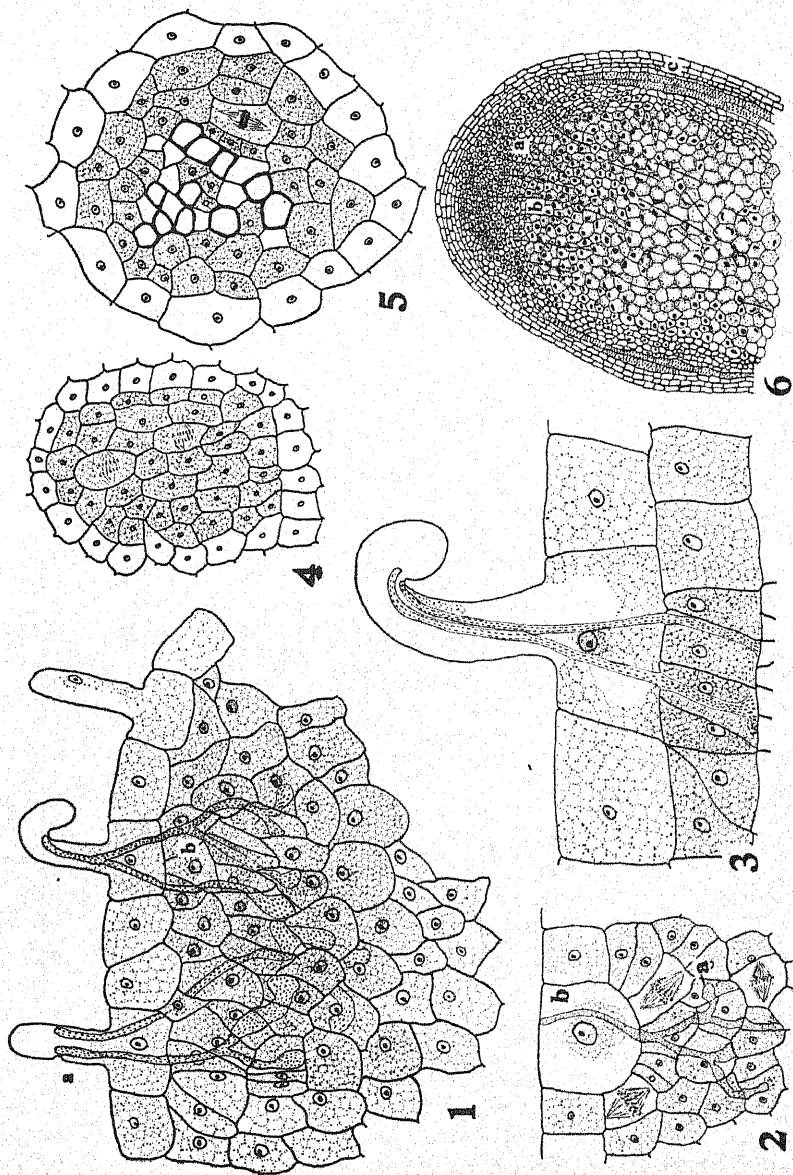
FIG. 17.—Formation of vascular bundle from procambial strand; longitudinal section of soybean nodule.  $\times 400$ .

FIG. 18.—Region of connection of vascular bundle to the central cylinder of the soybean.  $\times 115$ . (a) Protoxylem point. (b) Secondary xylem. (c) Cambial layer of root.

FIG. 19.—Cross section of a branch of a vascular bundle surrounding the infected area of soybean nodule.  $\times 330$ . (a) Xylem. (b) Phloem-like parenchyma. (c) Cortical parenchyma.

FIG. 20.—A section of a soybean nodule showing starch grains and vascular bundle.  $\times 100$ . (a) Bacteroid cells. (b) Vascular bundle. (c) Starch grains.







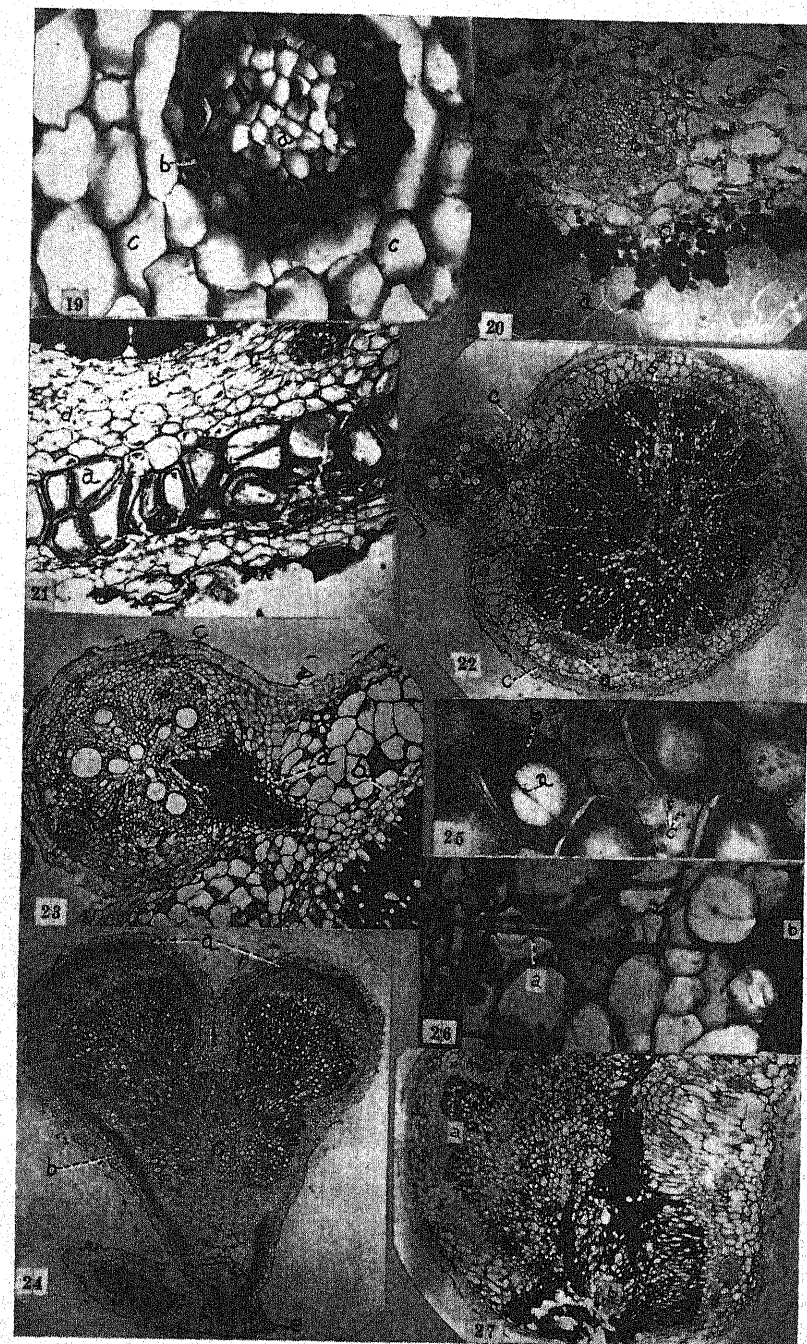
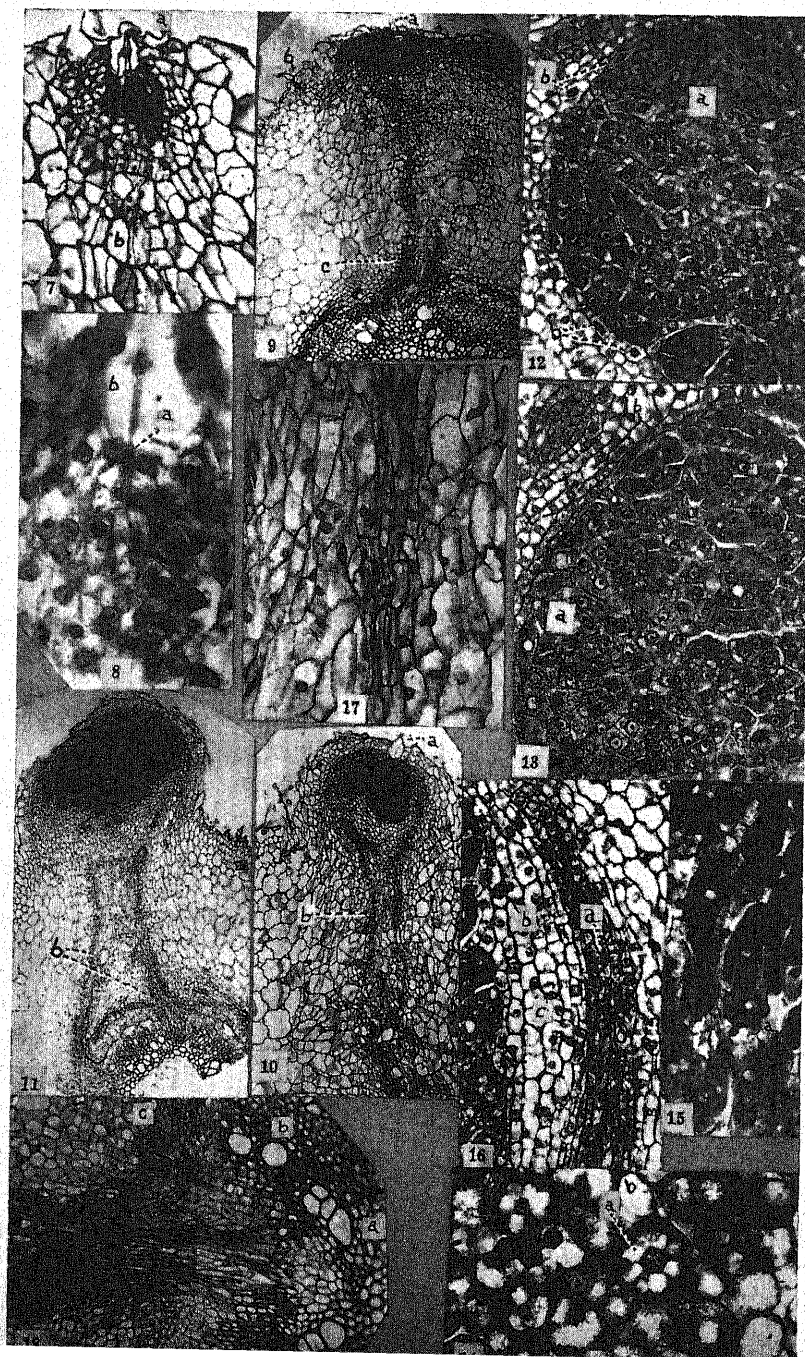


FIG. 21.—A mature soybean nodule with thick-walled cells in the parenchyma surrounding the bacteroidal tissue.  $\times 600$ . (a) Sclerenchyma. (b) Bacteroidal cells. (c) Vascular bundle. (d) Cortical parenchyma.

FIG. 22.—Cross section of nodule and root of the cowpea.  $\times 39$ . (a) Vascular bundles. (b) Cambial layer. (c) Cork layer. (d) Cross section of root. (e) Uninfected cells.

FIG. 23.—Portion of cowpea nodule showing cortical layer of root continuous with nodule.  $\times 94$ . (a) Vascular bundle. (b) Cambial layer. (c) Cork layer. (d) Protoxylem point.

FIG. 24.—Sweet clover nodule longitudinal section.  $\times 39$ . (a) Apical meristem. (b) Vascular bundle. (c) Old bacteroidal cells. (d) Newly + infected cells. (e) Root.

FIG. 25.—Bacteroidal cells of alfalfa nodule.  $\times 660$ . (a) Remains of infection strand across vacuole. (b) Disintegrating nucleus. (c) Starch in uninfected cells.

FIG. 26.—Cowpea nodule showing fungus entering epidermal layer and passing through the cortex and reaching the bacteroidal cells.  $\times 440$ . (a) Fungus hyphae. (b) Bacteroidal cells. (c) Cortical parenchyma.

FIG. 27.—Cowpea nodule showing disintegration caused by fungi while nodule is still in a stage of growth.  $\times 220$ . (a) Fungus infection. (b) Growing region.

old (Figs. 12 and 13). Mitosis occurs in all planes, and when cell division ceases, the infected cells increase to several times their normal size. A cambium-like layer surrounds the bacteroidal cells and permits their expansion (Fig. 12, b). Parenchyma cells that are meristematic surround the xylem in the bundles (Figs. 5 and 1, b). These two meristematic regions increase the tissue surrounding the bacteroidal area. Growth takes place acropetally until the vascular bundles are united at the apex. This acropetal growth accounts for the marked elongation of many bacteroidal cells (Fig. 15). A cork cambium originated in the outer layers of the cortical parenchyma. The cork cambium and cork layer are continuous with those of the root (Figs. 21, 22, and 23).

#### SCLERENCHYMA IN SOYBEAN NODULES

A conspicuous layer of sclerenchyma cells develops in the cortical parenchyma as the nodule matures (Fig. 21, a). This layer completely surrounds the vascular and bacteroidal tissue in the nodule and is connected to the libriform fibers in the root. The thickened walls are a result of successive layers of cellulose deposited on the primary walls of parenchyma cells. When thickening of the cell wall begins, the walls give a microchemical test for cellulose; however, they soon become lignified. The nucleus remains in the lumen of the cell after lignification. The development of this layer of sclerenchyma terminates the growth of the nodule. Such layers are not found in other legume nodules investigated. Embedded simple pits are very prominent in these thick-walled cells.

#### VACUOLES IN BACTEROIDAL TISSUE

Vacuoles occur rather abundantly in the older bacteroidal cells (Figs. 14, 15, and 20). Vacuole formation appears to be the first indication of cessation of cell division. In the area showing vacuoles, mitotic figures were not prevalent. In the mature nodules, vacuoles were not found in such abundance. Apparently they disappear as the

nodule reaches maturity. Vacuoles may form singly or in clusters around the nucleus (Fig. 14). A vacuole may enlarge to such an extent that it occupies most of the volume of the cell, crowding the nucleus, the remainder of the cytoplasm, and bacteria against the inner cell walls. In the mature nodule apparently the vacuoles disappear, permitting the bacteria and cytoplasm again to occupy the entire volume of the cell.

#### STARCH GRAINS IN NODULES

Fig. 20 shows a portion of a soybean nodule with starch grains stained with IKI. The starch grains are found most abundantly in normal cells scattered throughout the bacteroid tissue, in the vascular bundle and in cortical parenchyma near the bacteroid tissue. Many of the starch grains appear to be large tetrads. The starch did not always give the blue color with IKI, but a yellow and brown instead. According to Palladin (3), this is an indication of starch hydrolysis. In the young nodule, starch was not as abundant. When disintegration of the nodule begins, the starch grains again disappear.

#### NODULE DEVELOPMENT IN VETCH

Nodules on vetch are much smaller than soybean nodules and are club-shaped, frequently branched. The mode of infection in vetch is similar to that of the soybean. The infection strand may penetrate the cortex until it reaches the endodermis, since there is much less cortical parenchyma in roots of vetch than in soybean roots. However, vetch nodules arise in the cortex and not in the endodermis or pericycle. The origin of the vetch nodule is like that of the soybean.

#### DEVELOPMENT OF BACTEROIDAL TISSUE

Cell division in the bacteroidal tissue of vetch is not as obvious as in the soybean, and the infection strand does not lose its identity during nodule development. The bacteroidal tissue is increased mainly by the continual invasion of new tissue laid down by an apical meristem instead of by the division of infected cells (Fig. 6, a). The infection strands run parallel, spreading toward the apex. This accounts for the club-shaped nodule. If, during growth, some of the cambial cells in the periphery function at a different rate or cease dividing entirely, the result will be branching of the nodule. There is no other definite cambial region except at the apex.

#### VACUOLES IN VETCH NODULES

Vacuoles appear much earlier in the bacteroidal cells of vetch than of soybeans. They enlarge much more rapidly and frequently occupy half the volume of the cell. The bacteria and cytoplasm are crowded towards the walls of the cell and forced to occupy a much smaller volume, as illustrated in Figs. 24 and 25. From observations made, it appears that the vacuoles disintegrate after reaching a certain size. Nuclear behavior of infected cells appears to be rather inconspicuous. The nucleus becomes somewhat flattened against the vacuole and

gradually breaks up into fragments (see Fig. 25, b). According to Terby (5), the nucleolus is the first to disappear.

#### CONDUCTIVE TISSUE FORMATION AND CAMBIAL ACTIVITY

A vascular system is formed connecting the xylem and phloem with the nodule soon after infection has occurred. The vascular bundles develop from procambium strands laid down by the peripheral meristem (Fig. 6, c). The addition of the new xylem from a cambial cell is not as obvious as in the soybean nodule. Peirce (4) suggested that growth of the nodule is limited by the vascular system.

The branching of the nodule and growth from one meristematic region prevents the vascular bundle branches from uniting at the apex. The vascular bundles are separated from the bacteroidal cells by cortical parenchyma. Cambium-like cells, surrounding either the bacteroidal tissue or vascular bundles, are not obvious. Growth of the nodule continues through most of the growing season. The entire nodule is covered with a corky layer, continuous with the root, as shown in Fig. 24 of the sweet clover nodule.

#### UNINFECTED PARENCHYMA

Uninfected parenchyma cells were noted in the bacteroidal area. These uninfected cells do not enlarge markedly, and cell division was not apparent. These cells were derived from the apical meristem and infection strands failed to penetrate them. Considerable starch was stored in these cells, as well as in cortical parenchyma cells surrounding the bacteroidal area.

#### NODULE DEVELOPMENT IN COWPEA

Nodules of the cowpea are spherical and develop to about the size of a small pea (Fig. 22). Although their shape, origin, and development are almost identical with that of the soybean, they are not caused by the same organism. Cowpea seeds are easily inoculated and small nodules appear on the seedling in about 10 days. The cowpea nodules, like soybean nodules, arise in the cortical parenchyma. The infection strand is broken up by the dividing cells. The bacterial area increases by cell division, followed by a marked enlargement as in the soybean (Fig. 13). The bacteroidal cells in the cowpea increase to several times their normal size. Vacuoles are formed that can be seen very distinctly and behave like those in the soybean (Fig. 22). Starch grains were found in abundance in the uninfected cells in the bacteroidal area, in the cortical parenchyma, and in the phloem-like cells surrounding the xylem. Apparently the uninfected cells in the bacteroidal tissue divide, as a large number of such cells was prevalent in the bacteroidal area.

#### CONDUCTIVE TISSUE DEVELOPMENT AND CAMBIAL REGIONS

Vascular bundles are formed from procambium strands and completely surround the infected area (Figs. 22 and 23, a). Cells surrounding the vascular bundles retain their meristematic activity and add



new tissue to the bundle, as shown in Fig. 12 of the soybean. In the mature nodule, the vascular bundles unite at the apex. A cambium-like layer can be noted surrounding the infected area (Figs. 22, b and 23, b). A cork cambium is formed, and considerable corky tissue is laid down on the outside of the cortical parenchyma (Figs. 22 and 23, c). This cork cambium is continuous with the cork cambium of the root.

## NODULE DEVELOPMENT IN ALFALFA AND SWEET CLOVER

### FORM, ORIGIN, AND DEVELOPMENT

The root nodules of alfalfa and sweet clover are club-shaped and often branched (Fig. 24). In origin and development, they are almost identical with the vetch nodule. However, the nodules of alfalfa and sweet clover are usually in much larger clusters. In the bacteroidal tissue of alfalfa and sweet clover, cell division is not as obvious as in the soybean and cowpea. Infection strands can be noted in the enlarged bacteroidal cells (Fig. 25, a). Bacteria were not found in these old strands and apparently had escaped from the strand into the cytoplasm. The formation of vascular bundles around the cortex is the same as that of the vetch. Vacuoles appear somewhat more conspicuous than in the other nodules studied. Starch grains were found in abundance in the different regions of the nodules the same as in other nodules studied (Fig. 25, c).

## NODULE DEVELOPMENT IN PEANUT

The peanut forms nodules which are similar in origin, development, and structure to those of the soybean and cowpea. The peanut produces an abundance of nodules when inoculated. In shape, the nodules are spherical but do not grow as large as the soybean and cowpea nodules.

## FUNGI WITHIN THE NODULES

Filamentous fungi were found within the nodule of the soybean and cowpea. The fungus hyphae were septate and much larger than the infection strands. The hyphae penetrated the nodule, passing through the corky layer, cork cambium, cortical parenchyma, and reached the bacteroidal area (Fig. 26, a). From all indications these fungi are able to penetrate the nodule anywhere and do not depend upon a break in the epidermal layer. The cells through which the hyphae passed did not show any signs of necrosis until the fungi had reached the bacteroidal area. When the bacteroidal area is invaded, disintegration of the nodule apparently begins, although the nodule may continue its growth after it has been invaded by the fungi. Fig. 27 shows a nodule in which growth was taking place in one portion (a), while disintegration was occurring in other regions.

Nodules of various sizes were selected, sterilized with 5% formaldehyde, and kept at room temperature. In 5 days, 20% of the nodules were completely covered with a fungus mycelium that was exuding from the interior of the nodules. The fungus was of a light gray color

and was septate. Fruiting, however, was not obtained, thus making it impossible for identification. McCoy (2) reports finding fungi but that they were saprophytic.

#### SUMMARY

1. The nodule-forming bacteria were found to enter the host plant by the aid of an infection strand, usually through the root hairs, causing a characteristic curvature of the root hair as reported by other investigators; however, this curvature was not exhibited by all infected root hairs.

2. The bacteria-forming nodules may also enter the host through ordinary epidermal cells. Not all of the bacteria entering the host form nodules. The time at which infection can occur in the soybean is variable.

3. Large numbers of nodule-forming bacteria may retard the growth of a young seedling. The bacteria apparently are parasitic during early stages of nodule development and thereby interfere with the normal functioning of the root hairs.

4. The endodermis is not penetrated by nodule-forming bacteria in the leguminous plants studied and the nodules arise only in the cortical parenchyma and not in the pericycle, as do lateral roots as reported by some authors. Nodules formed on roots, which have only a few layers of cortical parenchyma cells, may appear to arise in the endodermis or pericycle.

5. The bacteroidal tissue in the soybean and cowpea nodules increases by division of infected cells. The infection strand is broken up by cell division and loses its identity. The bacteroidal tissue of alfalfa, sweet clover and vetch is mainly increased by the infection of new tissue which is continuously laid down by a meristem. The infection strand remains unbroken in the bacteroidal cells. Variation in the rate of cell division in the meristem will result in a branched nodule.

6. The older bacteroidal cells in the soybean and cowpea nodule lose their ability to divide and the nucleus disintegrates. Vacuoles which enlarge and crowd the bacteria and remaining contents against the inner cell are common in this tissue.

7. Vascular bundles are formed in the nodule, surrounding the bacteroidal cells and connecting with the xylem and phloem of the root. The vascular system develops from the cortical parenchyma by the formation of procambial strands. The vascular bundles are composed of xylem surrounded by phloem.

8. New xylem is continuously added to the vascular bundles of the soybean and cowpea. The vascular bundles of the soybean and cowpea unite at the apex, whereas in alfalfa, sweet clover, and vetch they do not unite.

9. In the soybean nodule a layer of sclerenchyma cells surrounding the bacteroidal and vascular tissues develops which limits the growth of the nodule. This layer of sclerenchyma tissue develops from the cortical parenchyma. It is not found in the cowpea, alfalfa, sweet clover, and vetch nodules.

10. Starch grains are present in abundance in the uninfected cells in the bacteroidal tissue and around the vascular bundles.

11. Filamentous fungi, which appeared to be parasitic because of their invasion of living cells, were found in the nodules. These fungus hyphae resemble the infection strands and may have been mistaken as such by earlier investigators.

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## RELATIVE EFFECTIVENESS OF CONTROLLING DIFFERENT PHYSIOLOGIC RACES OF BUNT BY SEED DISINFECTION<sup>1</sup>

J. FOSTER MARTIN and RODERICK SPRAGUE<sup>2</sup>

THE fact that physiologic races of *Tilletia tritici* (Bjerk.) Wint. and *T. levis* Kühn differing in pathogenicity exist in the Pacific Northwest was first reported by Stephens<sup>3</sup> in 1927. It was at once recognized that this greatly complicates the program for breeding smut-resistant wheat varieties and it is conceivable that it may make seed treatment more difficult. Such would be the case, for example, if it were found that physiologic races respond differently to seed treatment.

It seemed desirable to determine whether such is the case and experiments with this objective in view were begun in 1930. Since then, Holton and Heald<sup>4</sup> found some evidence to support the belief that copper carbonate controlled certain races better than others. The purpose of this paper is to report the results of the experiments begun in 1930. Petit<sup>5</sup>, however, reported in 1931 that various anti-septics had a similar effect on each of five bunt strains which he tested.

### MATERIALS AND METHODS

Experiments were conducted at Pendleton, Ore., in 1930, 1931, 1934, 1935, and 1936, and at Corvallis, Ore., in 1935 and 1936. The bunt races were selected on the basis of differences in pathogenicity. The race numbers are those assigned by Rodenhiser and Holton<sup>6</sup> with the exception of CL-27, CL-92, CT-28, and CT-117. These are collections made in eastern Oregon which have not been definitely classified.

Clean seed of Hybrid 128 and Goldcoin wheat was used for the experiments at Pendleton in 1930 and 1931 and of Hybrid 128 in all other experiments. Single 16-foot rows were used at Pendleton except in 1936. At Corvallis in 1935 and 1936 and at Pendleton in 1936, five 8-foot rows of each treatment were grown. Infection percentages were based on head counts, there being 300 to 700 heads in the 16-foot rows and about half this number in the 8-foot rows.

<sup>1</sup>Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Oregon Agricultural Experiment Station, Corvallis, Ore. Technical Paper No. 268 by approval of the Director of the Oregon Agricultural Experiment Station. Received for publication February 2, 1938.

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<sup>3</sup>STEPHENS, D. E. [Report of the Sherman County Branch Station, Moro, Ore., July 8, 1927.] U. S. Dept. of Agriculture, Bureau of Plant Industry, Division of Cereal Crops and Diseases Cereal Courier, 19:230. 1927. [Mimeographed.]

<sup>4</sup>HOLTON, C. S., and HEALD, F. D. Studies on the control and other aspects of bunt of wheat. Wash. Agr. Exp. Sta. Bul. 339. 1936.

<sup>5</sup>PETIT, A. Observations sur la carie du blé. Ann. Serv. Bot. [Tunis] 7:101-103. 1931. (Abs. in Rev. Appl. Mycol. 11:442-443. 1932.)

<sup>6</sup>RODENHISER, H. A., and HOLTON, C. S. Physiologic races of *Tilletia tritici* and *T. levis*. Jour. Agr. Res., 55:483-496. 1937.



For the experiments at Pendleton prior to 1936, the seed was heavily coated with bunt spores and the excess screened off. At Corvallis in 1935, 1 part by weight of inoculum to 100 parts of seed was used. Seed for Corvallis and Pendleton in 1936 was inoculated together, using 1 part inoculum to 200 parts of seed. The disinfectants were applied at the rates specified in Table 1. Only results from those disinfectants which are or have been commonly used by farmers for treating wheat are given. Several additional disinfectants were included at Pendleton in 1930, 1931, 1934, and 1935, but since they have not been and are unlikely to be made available for commercial use, and since results with them were similar to those with the disinfectants included in Table 1, they are omitted here.

### EXPERIMENTAL RESULTS

Considering first the copper carbonate treatments (both 52% and 18% copper), it will be noted (Table 1) that all races produced approximately equal percentages of smut, except that T-1, T-11, and L-7 at Pendleton in 1934 and T-11 at Corvallis in 1935 appear to have been controlled better by the treatment than other races. However, the untreated checks of these races also produced less smut than others and it seems more reasonable to assume, therefore, that the observed differences were due to differences in virulence of the races rather than to a differential response to copper carbonate. Probably the same explanation applies to the observed differences in the apparent better control of T-1, T-11, and L-7 for the Ceresan treatment at Pendleton in 1934. Race L-4 was less well controlled at Pendleton in 1930 and again in 1934, but in the other trials this was not the case.

New Improved Ceresan at Pendleton in 1936, when applied at the ½-ounce rate, seemed to control T-8 better than the other races, and the difference cannot be explained by differences in virulence as shown by the checks. However, at the 1-ounce rate, there was no difference in the effectiveness of the treatment for different races. Also, in all other tests with New Improved Ceresan, there is no evidence of a differential response to treatment.

Races T-10 and CL-27 produced more smut than did other races at Corvallis in 1935 when treated with basic copper sulfate, but similar differences did not appear in other tests.

Copper sulfate and formaldehyde effected good control in practically all cases and there are no differences between races that cannot easily be attributed to random errors or differences in corresponding untreated checks.

Altogether, the data here presented supply no convincing evidence that certain races are more or less easily controlled than others. This is true regardless of the fungicide used, except as such differences may be related to differences in virulence of the inoculum as shown by the untreated checks. A few profusely tillered smutted plants from seed that escaped the toxic action of the disinfectant may considerably increase the percentage of smutted heads.

These studies do not apply to conditions where the smut spores are present in the soil. Seed treated with the common disinfectants and planted on High Prairie, Wash., in 1937, on soil infected with spores of a race of *Tilletia tritici* which causes extreme dwarfing of the plants,



		Copper Carbonate (18% copper)													
Pendleton 1930 1931 1934 1935 1936 Corvallis 1935 1936	3	—	6.9	3.9	—	—	—	—	13.9	—	6.1	—	—	7.7	10.5
	3	—	2.8	7.5	—	—	—	—	6.7	—	—	—	—	5.7	4.5
	3	6.9	26.5	17.7	26.7	—	—	—	10.7	4.4	—	—	—	16.2	—
	3	42.3	6.1	14.2	32.5	—	—	—	27.8	11.7	—	—	—	20.4	—
	2	—	20.9	—	—	18.9	17.9	—	—	26.4	—	—	—	19.0	—
	2	—	—	—	33.0	7.9	47.3	—	—	35.5	—	—	—	31.4	—
		2	1.9	—	—	1.3	2.8	—	—	6.4	—	—	—	2.7	—
Ceresan															
Pendleton 1930 1934 1935	3	—	9.1	4.3	—	—	—	—	12.0	—	3.0	—	—	7.1	4.6
	3	4.0	17.7	8.5	17.3	2.9	—	—	6.1	20.5	5.2	—	—	10.3	—
	3	17.8	4.2	11.2	12.7	3.8	—	—	8.8	4.3	4.3	—	—	8.4	—
New Improved Ceresan															
Pendleton 1936 Corvallis 1935 1936 Pendleton 1936 Corvallis 1936	1/2	—	2.4	—	—	—	19.1	18.3	—	17.6	—	—	—	12.7	—
	1/2	—	—	—	1.4	—	1.5	4.1	—	4.1	—	—	—	2.7	—
	1/2	—	0.0	—	—	—	2.1	2.6	—	3.4	—	—	—	1.6	—
	1	—	0.3	—	—	—	1.4	1.1	—	0.9	—	—	—	0.7	—
	1	—	0.0	—	—	—	0.1	0.0	—	0.4	—	—	—	0.3	—
Basic Copper Sulfate															
Corvallis 1935 1935 1936 Pendleton 1936	3	—	—	—	15.0	3.4	9.2	—	—	4.9	—	—	—	9.6	—
	2	—	—	—	7.1	7.2	18.2	—	—	12.6	—	—	—	13.2	—
	2	—	1.2	—	—	0.7	1.9	—	—	0.7	—	—	—	0.9	—
Pendleton 1936	2	—	6.8	—	—	6.1	8.5	—	—	6.3	—	—	—	6.0	—
Copper Sulfate*															
Pendleton 1936 Corvallis 1935 1936	—	—	0.9	—	—	0.7	0.0	—	—	0.6	—	—	—	0.5	—
	—	—	—	—	4.1	0.4	0.6	—	—	0.0	—	—	—	1.4	—
	—	—	0.0	—	—	0.3	0.6	—	—	0.0	—	—	—	0.2	—
Formaldehyde†															
Pendleton 1936 Corvallis 1936	—	—	0.0	—	—	0.0	0.0	—	—	4.5	—	—	—	1.4	—
	—	—	0.0	—	—	0.0	0.2	—	—	0.4	—	—	—	0.2	—

\*One pound each of copper sulfate and common salt to 5 gallons of water followed by a lime bath.  
†Solution made up of 1 part formaldehyde to 320 parts of water.

gave results similar to those mentioned by Tingey and Woodward<sup>7</sup> in which seed treatment did not prevent infection by spores in the soil.

#### SUMMARY AND CONCLUSIONS

This paper reports results of 5 years' experiments in Oregon to determine whether some of the 12 physiologic races and collections of bunt (*Tilletia* spp.) tested could be more efficiently controlled than others by seed disinfection.

Under the environmental conditions at Pendleton and Corvallis, there were no consistent differences in relative effectiveness of controlling any of the races of bunt tested. The apparent relative efficacy of control of certain races shifted from one year to another. These differences are attributed to chance and to excess proliferation of "escaped" smutted plants. The greatest differences were noted where control was not good, which also may be attributable to greater chance fluctuation. A positive relationship was found between the amount of bunt in the untreated check rows and the effectiveness of control by seed disinfection.

<sup>7</sup>TINGEY, D. C., and WOODWARD, R. W. Relief wheat. Utah Agr. Exp. Sta. Bul. 264. 1935.

# WATER REQUIREMENT OF WHEAT AS INFLUENCED BY THE FERTILITY OF THE SOIL<sup>1</sup>

B. N. SINGH and B. K. MEHTA<sup>2</sup>

THE relation between water requirement of crops and the fertility of the soil has been investigated by several workers. Reed (1)<sup>3</sup> found that potash fertilizers had a tendency to reduce the quantity of water needed for unit dry matter production of crop plants, while Hartwell (2) recorded results contrary to those of Reed. Leather (3, 4) came to the conclusion that the addition of fertilizers and manures decreased the water requirement of plants grown in jars but had no marked effect on field plots.

Montgomery and Kiesselbach (5) and Kiesselbach (6) have dealt with the problem of water requirement in America. They found that when manure was added to the soils of different degrees of fertility the water requirement was decreased, the greatest decrease occurring with the least fertile soil.

TABLE I.—Water requirement and yield under various manurial treatments.

Treatment	Transpiration per plant, kilograms	Yield per plant, grams	Water requirement based on	
			Dry matter, grams	Yield, grams
Wood ash.....	4.228	2.982	460.05	1,497.4
Pigeon extra.....	4.289	2.984	456.77	1,437.2
Leaf mould.....	4.881	3.071	440.96	1,589.3
Control.....	4.078	3.141	449.58	1,497.4
Rape seed cake.....	5.976	4.377	480.02	1,365.3
Night soil.....	5.932	4.491	430.15	1,320.8
Ammonium sulfate + potassium sulfate and basal dressing of <i>C. juncea</i> .....	7.712	4.864	459.84	1,585.5
Cow dung.....	6.870	4.937	447.10	1,391.6
Castor cake.....	6.351	5.027	416.97	1,263.7
<i>C. juncea</i> .....	6.613	5.083	433.61	1,301.0
Ammonium sulfate + potassium sulfate.....	7.809	5.238	435.01	1,490.9
Farm yard manure.....	6.939	5.312	426.98	1,276.5
Sheep dung.....	6.395	5.572	365.59	1,147.6
Superphosphate + potassium sulfate.....	6.556	6.007	373.00	1,091.4
Linseed cake.....	7.830	6.505	400.94	1,203.7
Neem (margosa) cake.....	6.517	6.719	319.01	969.9
Safflower cake.....	8.060	6.813	389.94	1,183.0
Superphosphate + ammonium sulfate.....	10.320	9.695	345.46	1,064.4

<sup>1</sup>Contribution from the Institute of Agricultural Research, Benares Hindu University, Benares, India. Received for publication February 3, 1938.

<sup>2</sup>Director and Associate, respectively.

<sup>3</sup>Figures in parenthesis refer to "Literature Cited", p. 398.

Singh, *et al.* (7) and Singh and Singh (8) have recently presented some results on the water requirement of crops in India, but aspects other than manuring were investigated.

In the present paper are presented some data obtained in connection with an attempt to find a quantitative relation between water requirement and soil fertility. A variability in the soil fertility was in-

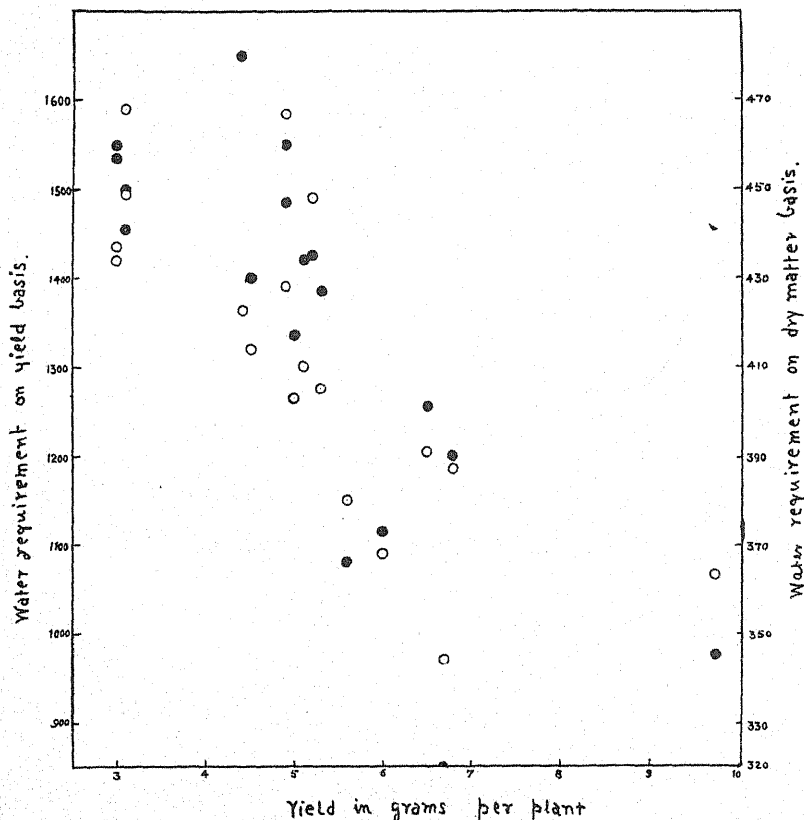


FIG. 1.—Correlation between yield and water requirement. Dots refer to water requirement on the basis of total dry matter production, whereas the circles represent that calculated on the basis of yield of grain.

duced by the application of different manures, both inorganic and organic, in concentrated as well as in bulky forms. The yield of wheat under various manurial treatments provided a quantitative measure of expressing the fertility of the soil.

The manures selected for experimentation may be roughly classified in four groups, *viz.*, (a) farm yard manure, green manure (*Crotalaria juncea*), leaf mould, and wood ash; (b) night soil, cow dung, sheep dung, and pigeon excreta; (c) safflower cake, rape seed cake, linseed cake, castor cake, and neem (*margosa*) cake; and (d) ammonium sulfate plus superphosphate, ammonium sulfate plus potassium sulfate,

ammonium sulfate plus potassium sulfate with a basal dressing of *Crotalaria juncea*, and superphosphate plus potassium sulfate.

Earthenware pots 10 by 12 inches in size were selected and glazed on the outside to minimize the loss of manurial ingredients. The organic bulky manures in well-rotted, friable condition were mixed with well-sieved farm soil, a typical loam, in the proportion of 1 to 2 parts, respectively, and the mixture utilized for filling up the pots. Oilcakes were powdered first and mixed with the soil in the proportion

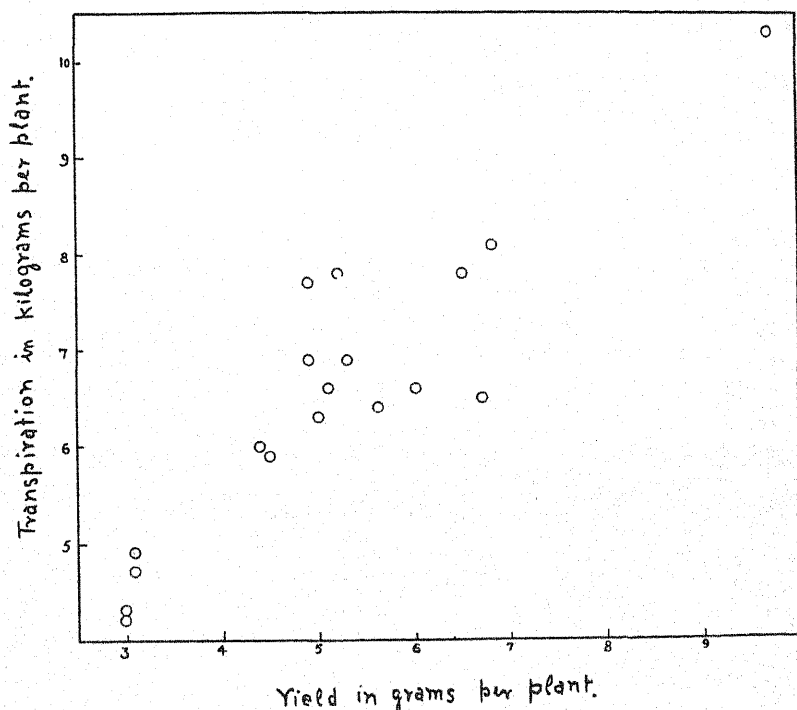


FIG. 2.—Correlation between yield and transpiration

of 4 ounces of manure for each pot. The combinations of chemical fertilizers were in the proportion of 1 to 1 and the total quantity per pot was 8 grams.

Care was taken to ensure that the organic manures had perfectly decomposed before sowing the wheat seed (variety Pusa 4). The method employed for determining the water requirement has already been given by Singh, *et al.* (7).

## RESULTS

Data regarding the yield of wheat under various manurial treatments and the corresponding values for water requirement are given in Table 1. It is evident that by means of the manurial combinations

a fairly marked variability was introduced in the degree of fertility of the soil. For example, the yield per plant with wood ash was 2.982 grams as against 9.695 grams with superphosphate plus ammonium sulfate.

Data contained in Table 1 have been presented graphically in Figs. 1 and 2. Fig. 1 shows the relation between the water requirement and yield of wheat. As yield provides a measure of the fertility of the soil, it is evident that there is a correlation between low water requirement and high yield. Fig. 2, on the other hand, shows the relation between the quantity of water transpired in one growing season by one wheat plant and the yield. It is evident that there is a correlation between high water expenditure and high degree of fertility.

To sum up, increasing the fertility of the soil by addition of manures reduces the quantity of water needed for unit dry matter production, but enhances the total quantity of water transpired by the crop.

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## SURVIVAL OF WHEAT VARIETIES IN THE GREAT PLAINS WINTERHARDINESS NURSERY, 1930-1937<sup>1</sup>

K. S. QUISENBERRY<sup>2</sup>

A uniform winterhardiness nursery has been grown at from 20 to 30 experiment stations in the Great Plains of the United States and Canada each year since 1919. The purpose has been to obtain information on the relative winterhardiness of new wheats as rapidly as possible. Results of the first 10 years of the experiment have been published.<sup>3</sup>

Data from seven additional years have now been obtained. At the close of each season a mimeographed summary of the current year's data has been prepared and sent to all cooperators. The annual reports are often preliminary, but furnish the current data from the individual stations. Because no period of years summary has been published since 1930 and because of regional interest in the data, the present summary is presented.

Yields were taken at some stations, but as not all nurseries were grown in multiple-row plats and since in many cases yield is directly correlated with survival, the yield data are not given.

### SCOPE OF INVESTIGATIONS

The methods employed were substantially the same as in earlier work and have been thoroughly described in the previous reports. In all nurseries the strains were grown in three or more replications. In some cases there were only single rows, while in others there were 3-row blocks. Insofar as possible, all seed was raised at the Kansas Agricultural Experiment Station, Manhattan, Kans. When this source failed to supply sufficient seed of any variety, the deficit was made up from North Platte and Lincoln, Nebr., or from Moccasin, Mont. In most cases seed of new varieties for the first year was grown at the station at which the variety originated.

### METHODS

The relative winterhardiness data presented in this report are based, for the most part, on visual estimates of survival in the spring rather than on actual counts. Actual counts are desirable where the seed has been spaced and where large numbers of plants may be counted. In these nurseries the seed was not spaced, and if good stands were obtained, counts would have been very difficult to make. It is felt that in this case an estimate of survival, based on observation at the time growth starts in the spring, gives the most accurate figure on survival.

<sup>1</sup>Contribution from the Division of Cereal Crops and Diseases, U. S. Dept. of Agriculture. Received for publication February 10, 1938.

<sup>2</sup>Agronomist.

<sup>3</sup>CLARK, J. A., MARTIN, J. H., and PARKER, J. H. Comparative hardiness of winter wheat varieties. U. S. D. A. Cir. 378. 1926.

QUISENBERRY, KARL S., and CLARK, J. ALLEN. Hardiness and yield of winter wheat varieties. U. S. D. A. Cir. 141. 1930.

TABLE 1.—Annual and average percentage of survival of 66 varieties of winter wheat grown in the Great Plains winterhardness nursery during one or more years from 1930 to 1937 and the percentage of Kharkof (C. I. 1442) for the period from 1920 to 1937.\*

Variety	State or hybrid No.	C. I. No.	Percentage survival in								Weighted average %	Khar-kof same years, %	No. sta-tion years	Per-cent- age of Khar-kof	1920-37			
															No. sta-tion years	Per-cent- age of Khar-kof	N. of sta-tion years	Per-cent- age of Khar-kof
			1930	1931	1932	1933	1934	1935	1936	1937								
			24†	22†	26†	20†	8†	16†	14†	10†								
Hard Red Winter																		
inhardt X Minturki. . . . .	Minn. No. 2312	8215	74.9	84.2	71.3	62.8	51.6						71.7	100	124.7	141	125.2	
urkey X Minessa. . . . .		8887	72.3	84.2	72.1	60.9	49.0	83.4					72.5	116	123.3	121	121.2	
inard X Minhardt. . . . .	Minn. No. 2272	8218	70.9	83.9	72.0	62.5	48.6						70.6	100	122.8	112	119.2	
unred X Minhardt. . . . .		8040	74.7	84.4	71.2								76.4	72	122.8	112	119.2	
ureka X Minhardt. . . . .		8042	72.5	84.7	71.3								75.8	72	121.9	132	120.7	
inard X Minhardt. . . . .	Minn. No. 2313	8888	70.5	84.8	70.3								75.8	72	121.9	132	120.7	
heat X Rye. . . . .	Alberta I-27-11	11503				55.4	40.6	84.7	64.9				74.0	112	120.9	—	—	
inhardt X Minturki. . . . .		8034	71.4	83.3	70.3								63.7	58	120.6	—	—	
unred X Minessa. . . . .		8045				61.5	44.3	80.8	61.4	61.4			74.6	72	119.4	150	118.3	
urkey X Minessa. . . . .	Nursery No. 48	11505				57.5	43.6	80.1					63.2	68	119.0	—	—	
inard X Minhardt. . . . .	Minn. No. 2314	8889	69.4	81.8	69.6	58.3	49.0						68.3	53.1	118.8	—	—	
ago. . . . .		8033	70.5	82.4									76.2	57.5	118.0	124	119.2	
unred X Minhardt. . . . .	19102 IX-5	11726											76.2	46	118.0	—	—	
inturki. . . . .	Minn. No. 1507	6155	68.9	79.7	68.2	57.9	45.4	79.6	61.8	59.6	64.3	63.9	64.1	24	117.8	—	—	
inturki X Marquis. . . . .	Minn. No. 2614	11502				53.6	40.4	82.9	59.1	65.3	67.4		58.0	140	116.2	290	117.7	
inturki X Turkey. . . . .	Wis. No. 81-26	11500				56.5	37.3	86.5	55.9	60.0	61.7		53.6	68	115.3	—	—	
heat X Rye. . . . .	Alberta I-27-12	11504				54.9	34.6	81.7					53.6	68	115.1	—	—	
inturki X Marquis. . . . .	Minn. No. 2618	11659						80.7	60.6	58.1	61.0		53.1	44	114.9	—	—	
inturki X Marquis. . . . .	Minn. No. 2616	11501				52.2	40.8	84.1	58.0	63.6	68.0		59.3	40	114.7	—	—	
inturki X Marquis. . . . .	Minn. No. 2615	11658						77.8	61.6	60.0	61.2		53.6	68	114.2	—	—	
urkey. . . . .	Minn. No. 1488	6152	66.6	80.3	66.6	53.8	40.8				67.7		59.3	40	113.0	250	112.8	
urkey selection. . . . .	Nebr. No. 1063	10094				41.6	79.0	59.6	59.6		65.0		57.5	100	113.0	—	—	
											63.1		56.1	48	112.5	—	—	

Turkey X Buffum	So. Dak. No. 11-29-25-4	11739								64.7	57.8	10	111.9		
Turkey X Kanred	B. H. 25-1	11725								60.7	54.4	24	111.6		
Minhardi X Marquis	Minn. No. 2551	11657								66.0	59.3	40	111.3		
Belogolina		1543	67.4	76.2	63.1					68.5	62.2	72	110.1	165	
Cheyenne selection	Nebr. No. 1087	11666								59.7	54.4	24	109.7		
Wisconsin sel. 21-25	Wis. No. 21-25	10018								63.1	58.4	92	108.0		
Turkey selection	Nebr. No. 1062	10015								62.9	58.5	68	107.5		
Nebraska No. 60	Nebr. No. 60	6250	60.9	74.9	62.4	50.0	42.9	75.1	55.8	59.0	58.0	140	106.6	290	107.1
Turkey X Buffum	So. Dak. No. 11-29-37-2	11741								61.6	57.8	10	106.6		
Turkey selection	Nebr. No. 1069	10016								60.9	57.5	106	105.9		
Wheat X Rye	N. Dak. No. 2309	8890	63.3								60.3	24	105.0		
Belogolina selection	North Platte No. 11	8894	59.9	74.1	62.0					65.0	62.2	72	104.5		
Wheat X Rye (Meister)		11493								56.4	54.4	24	103.7		
Cheyenne	Nebr. No. 1050	8855	57.9	73.7	61.2	45.8	39.6	74.8	53.7	59.2	58.0	140	102.9		
Kanred		5146	59.9	69.4	61.0	47.0	36.3	78.6	52.1	56.5	58.0	140	102.8	290	102.9
Oro		8220	60.0	71.4	60.1				63.5	62.2	62.2	72	102.1	113	101.2
Turkey X Galgalos		11540	60.3	69.3	58.0	47.4	40.5	66.6	49.6	57.8	55.7	38	101.8		
Kharkof		1442	59.7						51.9	57.8	58.0	140	100.0	290	100.0
Newturk		6935	58.7							59.7	60.3	24	99.0	133	98.3
Karmont		6700	58.7							58.7	60.3	24	97.3	165	99.3
Iowin	Iowa No. 2025	10017								54.6	57.3	106	95.0		
Ashkof X Minturki	Wis. No. 312.27														
Kawale X Tenmarq	28.1-29.13	11724								51.5	54.4	24	94.7		
Blackhull selection	Nebr. No. 1086	11669								53.7	57.8	10	92.9		
Kanred X Hard Fed	Nebr. No. 1093	11737								52.9	57.8	10	91.5		
	Kans. No. 2679	11735								50.2	54.9	70	91.4		

\*The hearty cooperation of the following persons in obtaining the data from the various stations is gratefully acknowledged: John H. Parker, Manhattan, Kans.; A. F. Swanson, Hays, Kans.; E. H. Coles, Colby, Kans.; J. J. Curtis, Akron, Colo.; L. C. Burnett, Ames, Iowa; C. A. Suneson and T. A. Kieselbach, Lincoln, Nebr.; N. E. Jordon and L. L. Zook, North Platte, Nebr.; C. A. Suneson, Alliance, Neb.; A. L. Nelson, Archer, Wyo.; Glenn Hartman, Laramie, Wyo.; E. J. Delwiche, Ashland, Wis.; E. R. Ausemus and H. K. Hayes, St. Paul, Minn.; E. R. Ausemus and R. E. Hodgson, Waseca, Minn.; E. R. Ausemus, Duluth, Minn.; K. H. Klages and S. P. Swenson, Brookings and Highmore, S. Dak.; E. S. McFadden, Redfield, S. Dak.; L. R. Waldron, Fargo, N. Dak.; Glenn S. Smith, Langdon, N. Dak.; V. C. Hubbard and J. C. Brinsmade, Jr., Mandan, N. Dak.; R. W. Smith, Dickinson, N. Dak.; W. B. Nelson and R. H. Bamberg, Bozeman, Mont.; J. L. Sutherland and R. H. Bamberg, Moccasin, Mont.; M. A. Bell and J. J. Sturm, Havre, Mont.; W. J. Breakey, Morden, Manitoba; J. G. Davidson, Indian Head, Sask.; H. J. Kemp, Swift Current, Sask.; J. B. Harrington, Saskatoon, Sask.; W. D. Hay, Lethbridge, Alta.; O. S. Aamodt and K. W. Neatby, Edmonton, Alta.

†Number of stations reporting.

TABLE I.—Continued.

Variety	State or hybrid No.	C. I. No.	Percentage survival in								Weighted average %	Khar-kof same years, %	No. sta-tion years	Per-cent- age of Khar-kof	1920-37	
															No. of sta- age of Khar- kof years	Per-cent- age of Khar-kof
			1930	1931	1932	1933	1934	1935	1936	1937						
			24†	22†	26†	20†	8†	16†	14†	10†						
Hard Red Winter																
Akron selection.....	Akron No. 7	11660							48.1	50.7	49.2	54.4	24	—	—	—
Canred X Hard Fed.....	Kans. No. 2673	10092					28.9	67.7	41.9		50.0	55.7	38	—	—	—
1066-1 X Burbank.....		10087				40.0				48.8	40.0	47.4	20	—	—	—
Wisconsin sel. 18-4.....	Kans. No. 2729	11673									48.8	57.8	10	—	—	—
Quivira.....	Wis. No. 18.4	10019			58.0						58.0	69.3	22	—	—	—
Canred X Hard Fed.....	Kans. No. 2628	8886	47.9	52.0	47.8	43.5	31.8	65.6	36.6		47.9	58.0	130	—	—	—
Blackhull.....	Kans. No. 2728	11672							47.5		47.5	57.8	10	—	—	—
Blackhull.....	Kans. No. 2672	10091				32.2	30.8	63.1			43.2	53.1	44	—	—	—
Blackhull.....		6251	45.9	54.3	47.9	35.1	30.0	61.9	34.8	44.5	45.8	58.0	140	—	—	281
Blackhull.....		6936	47.1	50.0	50.3						49.1	62.2	72	—	—	181
Blackhull.....		8856	40.5								40.5	60.3	24	—	—	70.9
Blackhull.....		10089				28.0					28.0	47.4	20	—	—	—
Blackhull.....		11374			32.9						32.9	58.0	26	—	—	—
Soft Red Winter																
Autescens 0329.....		8896				71.6	45.5	87.9	65.5	76.6	71.8	53.6	68	—	—	—
Buffum No. 17.....		3330	75.2								75.2	60.3	24	—	—	124.7
Minhardi.....		5149	70.5	83.0	70.2	60.9	44.9	88.6	65.4	75.3	71.5	58.0	140	—	—	290
Canvale.....		8180	54.5	64.5	56.3						58.2	62.2	72	—	—	93.5
Calcaster.....		6471	45.6	56.4	47.7	38.0	31.4	54.3	29.9	38.2	44.7	58.0	140	—	—	218

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†Number of stations reporting.

For the most part varieties have been kept in the nursery only long enough to establish their relative hardiness. A few have remained constant to serve as checks and also for studies relating to the causes of winterkilling in different areas and in different years.

At some stations and in some seasons there was no killing and at others killing was complete. It is obvious that in these cases no information was obtained on varietal differences so these data are not included in the averages, thus the data from a varying number of stations are eliminated each year.

There may be some question as to the propriety of averaging data from several stations for a given year, since the causes of winter killing may be different and the data may not be entirely comparable. For the area as a whole, direct freezing appears to be the principal cause of killing, although at a few stations and in some years drouth is an important additional cause. Enough has been learned from detailed studies to justify the belief that for the determination of the relative winterhardiness of the varieties for the area as a whole, no serious error is introduced by using the average of the various stations.

### EXPERIMENTAL RESULTS

A summary of the data is presented in Table 1. For each year the number of stations reporting differential killing is shown. This number varied from 8 in 1934 to 26 in 1932. For each variety is shown an average (weighted for number of stations) for the period grown, together with an average for Kharkof (C. I. 1442) for the same period. Because the varieties were not all grown for the same period of years, and to make comparison easy, the relative winterhardiness is presented as a percentage of Kharkof. It is realized that this method may be open to criticism, but it has some merit.

The varieties are separated into hard and soft red winters depending on the character of the grain. Within each group the varieties are listed in order of relative hardiness based on the percentages of Kharkof for the period 1930-37. Some strains were grown in the nursery before 1930 and for these there is given a percentage of Kharkof for years grown between 1920-37. For the most part this figure does not vary greatly from the one for the period 1930-37.

A total of 61 hard and 5 soft red winter wheats were grown during all or part of the period from 1930 to 1937. Of these 66 varieties, 43 were more hardy than Kharkof. Only four varieties, two hard and two soft, had average survivals equal to or better than Minhardi, the hardy check, although several hybrid strains are nearly equal to Minhardi. Among the hard red varieties all of the more hardy strains are of hybrid origin, most of them having Minhardi as one parent. These represent lines which combine winterhardiness with quality and yielding ability for the more northern areas. Fourteen strains are as hardy as or more hardy than Minturki, a commercial variety grown in Minnesota. Of these, nine are hybrids of which Minhardi is one parent and three are hybrids of which Minessa is one parent.

Four wheat  $\times$  rye hybrids have been tested. Three of these, C. I. 8890, 11503, and 11504, proved to be more hardy than Kharkof, but none shows any rye characters. The other wheat  $\times$  rye hybrid (Meister's amphidiploid) shows rye characters but is only slightly more

hardy than Kharkof. The factors for extreme winterhardiness present in our best ryes do not seem to have been recovered in any of these hybrid strains.

Three strains of Minturki  $\times$  Marquis and one of Minhardi  $\times$  Marquis from Minnesota have been tested. None of these is quite equal to Minturki in hardiness, but all are distinctly more hardy than Kharkof.

Nebraska No. 60, Cheyenne, Kanred, and Oro are commercial varieties, all of which are slightly more winterhardy than Kharkof. Among the commercial varieties less hardy than Kharkof, the following are listed in order of hardiness: Iowin, Quivira, Blackhull, Tenmarq, and Early Blackhull. Blackhull and Tenmarq are about equal in winterhardiness, but Early Blackhull is decidedly tender, being among the least hardy of those tested. Two Oro  $\times$  Tenmarq strains seem to be slightly more hardy than Tenmarq but decidedly less hardy than Oro. Both of these wheats are resistant to certain races of bunt.

Only four varieties of soft red winter wheat were tested. *Lutescens* 0329, Buffum No. 17, and Minhardi are all very hardy. *Lutescens* 0329 has the highest percentage of Kharkof of any variety in the nursery, due in part to a very high average survival in 1933. Since that time its average has been about equal to that of Minhardi. This variety was developed by selection in the U. S. S. R. where it is one of the most hardy wheats. Here it is very late and yields poorly under most conditions. Kawvale, a semi-hard variety, is slightly less hardy than Kharkof, although more hardy than Blackhull and Quivira. Fulcaster is one of the more tender varieties grown.

A study of the data shows that between the tender varieties, such as Early Blackhull, Fulcaster, and Tenmarq, and the most hardy ones, such as *Lutescens* 0329 and Minhardi, there is a series of wheats possessing gradually increasing degrees of winterhardiness. In a previous publication,<sup>4</sup> it was suggested that varieties could be classified roughly into four groups for winterhardiness, *viz.*, very hardy, mid-hardy, slightly hardy, and tender. Such a classification is, of course, arbitrary and with the present data rather difficult.

*Lutescens* 0329, Minhardi, and one or two hybrid strains undoubtedly make up a group materially more hardy than the remainder. Minturki, Turkey (C. I. 6152), Turkey selection (C. I. 10094), and Nebraska No. 60 are less hardy than the first group. A third group would contain varieties about equal to Kharkof in hardiness. Cheyenne, Kanred, Oro, and Newturk can be placed in this group. The tender group would contain Quivira, Blackhull, Tenmarq, Early Blackhull, and other strains with nearly similar survivals. Thus it is seen that the varieties may be grouped in a general way with respect to hardiness, but between the groups mentioned or any other groups that might be made are many strains that could be classed one way or another, depending on variations from year to year.

A large number of hybrids have been made and studied by both state and federal stations with the object of producing wheats containing more winterhardiness. So far no strains are known that are

<sup>4</sup>See footnote 3, Quisenberry and Clark.

more hardy than *Lutescens* 0329 and Minhardi, and from this standpoint the work has been disappointing. Progress has been made, however, in the combining of hardiness and grain quality and yield. A number of lines are available that are nearly equal to Minhardi for winterhardiness and in addition are hard red winter wheats which give good yields in the more northern areas of the United States and in southern Canada. A constant search is being made for wheats that may have factors for hardiness differing from those now present in hardy wheats.

#### SUMMARY

A uniform winterhardiness nursery has been grown in the Great Plains of the northern United States and in Canada since 1919. A summary of the data from 1930 to 1937 is presented.

The object of the nursery is to obtain information on the relative winterhardiness of various varieties of winter wheat.

*Lutescens* 0329, Buffum No. 17, and Minhardi are the most hardy winter wheats available. Some hybrid strains seem to combine quality of grain and yield with relatively high winterhardiness.

In a general way the varieties studied may be placed in four groups for hardiness: *Lutescens* 0329 and Minhardi and a few hybrid strains in the hardy group; Minturki, Turkey (C. I. 6152), and Nebraska No. 60 in the mid-hardy group; Cheyenne, Kanred, Oro, and Kharkof in the slightly hardy group; and Quivira, Blackhull, Tenmarq, and Early Blackhull in the tender group. Between the extremes the varieties may be arranged in a gradually descending series from hardy to tender.

1. To study the effects of inbreeding on rye.
2. To determine the amount of progress that can be made by continued selection within selfed lines, for fertility, yield, vigor, and resistance to disease.
3. To determine the extent of hybrid vigor after crossing certain inbred lines.
4. To determine the effect of inbreeding on vigor and fertility in vigorous hybrids.
5. To obtain, finally, a rye having desirable agronomic attributes which can be maintained through open-pollination.

## MATERIALS AND METHODS

### SOURCES OF PARENT STOCKS AND HYBRIDS

The rye used in this experiment came from two sources, Schlansted and Abruzzes. The Schlansted was grown at the Experiment Station for several years under the number Pedigree 2. The lines of the Schlansted used in this experiment for inbreeding were chosen from several plants isolated in 1922 and continuously selected in open-pollinated head rows. Seven lines were composited and named Imperial, as noted above. Others of this group were bagged and used in this experiment on inbreeding. Since 1934, all new inbred lines have originated from the Imperial rye. A second source was several inbred selections and crosses within Abruzzes rye which were obtained in 1929 from E. B. Mains who was then at the Indiana Experiment Station. Some of the crosses made in 1932 were between inbred lines from the Wisconsin Pedigree 2 and Abruzzes selections of Mains. The crosses still being carried on from this combination are  $\times 7$ ,  $\times 9$ , and  $\times 11$ . All the other hybrids are from crosses between different inbred lines which were originally selected from the Wisconsin Pedigree 2 stock.

### TECHNIC OF INBREEDING

Different methods of bagging heads for the purpose of inbreeding were tried, such as covering individual heads in light weight paper or glassine bags; or groups of heads from the same plant with cheesecloth, cellophane, or 12-pound manila bags. The manila bag was found the most satisfactory. At planting time the seeds were spaced about 6 or 8 inches apart in the row. Just before heading, usually the last week in May, a stake about 1 inch  $\times$  2 inches  $\times$  5 feet was driven in the ground alongside the larger and more vigorous plants. Just before anthesis, heads were bagged and tied to the stake. As the plants grew, the bags were elevated every two or three days and tapped to scatter the pollen inside. The total flowers on each head were counted and from this the percentage of fertility calculated. The lines having the highest percentage of fertility and plumpest and best appearing seed and those that were purest for absence of color were selected for planting the following season.

### TECHNIC OF HYBRIDIZING

While some hand pollination was practiced, this plan was discontinued in favor of mass hybridizing. Hand pollination is slow and tedious and gives too few individual parental hybrids and only a small quantity of seed. For mass hybridization a special breeding block was laid out. Seeds were space planted in the row 6 to 8 inches apart and seed of another selection to be used in crossing was planted in the adjacent row a foot away. Planting was so arranged that each line was



adjacent to every other line that was to be crossed. Just before flowering, a stake was driven between every pair of plants chosen for crossing. Only the vigorous plants were chosen for parents. The heads of the two plants were tied together under one bag and the same attention given to raising and tapping the bags as was done with the inbreds. This scheme of cross pollination gave numerous seeds from which, in the following year's crop, the vigorous hybrids could be selected. While no claim can be made as to which were female and male parents, and even crossing would not be assured by this method, yet the procedure afforded an opportunity for producing hybrid material in greater quantities than by hand pollination.

#### RESULTS OF INBREEDING IN OPEN-POLLINATED RYE

In the selfed lines, segregation of characters other than fertility was observed. Some of these characters are as follows: Dwarfs (Fig. 1); malformed head or leaf; disease reaction; physiological spotting; low vigor; long slender heads; unusually wide heads; broad leaves; narrow leaves; large or small stems; light or dark green plants; leafy plants good for grazing; and size, shape, and color of kernel (Fig. 2). Many of the segregating characters were undesirable; therefore it is evident that selection of plants having agronomically desirable characters would rapidly reduce the number of lines.

Variable kernel size and shape seem to be characteristic of certain inbred lines. In Fig. 2a are shown kernels from sister selections that were apparently still segregating after 10 years of inbreeding. Vigor in vegetative growth of inbreds for the most part is less than in open-pollinated rye. Some of the inbreds were so poor that they could hardly be reproduced; but some of the more promising inbreds approached the vigor of the open-pollinated, as can be noted in Fig. 3.

Field experiments of this nature are always subject to error from causes which cannot be entirely controlled, *viz.*, foreign pollen lodging in florets before bagging; influence of bagging; and various environmental effects, such as excessive heat and rains. As variations due to these factors do not affect all plants alike, it would seem that averages of several lines should be more significant than values based on individual plants.

In 1934 and 1935 several lines were found among the first year inbreds having all heads completely sterile. An estimate was made of the number of these lines.

Table 1 gives the number of flowers observed, the number fertile, and the percentage of fertility for each year of selfing; also the total flowers, the total number fertile, and the average percentage fertility.

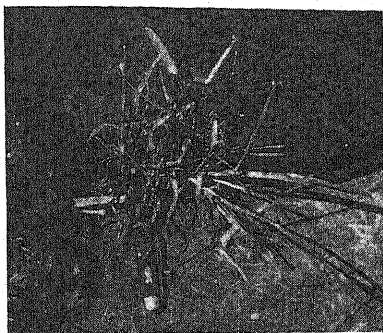


FIG. 1.—Dwarfed rye plant. Dwarfed and other undesirable types appear after inbreeding.

TABLE I.—*Summary of fertility percentage in selfed rye undergoing continuous selection for fertility.*

Year	No. of years selfed	Flowers observed		Percentage fertile
		Total	Fertile	
1926.....	1	16,953	253	1.5
1927.....	1	34,301	1,574	4.6
1934*.....	1	7,198	183	2.5
1935*.....	1	13,479	424	3.1
1936.....	1	8,810	436	4.9
1937.....	1	7,872	392	2.0
Total or average.....	—	80,613	3,262	4.0
1927.....	2	14,398	290	2.0
1928.....	2	130,166	4,995	3.8
1935.....	2	10,816	512	4.7
1936.....	2	5,612	143	2.6
1937.....	2	13,663	524	3.8
Total or average.....	—	174,655	6,464	3.7
1928.....	3	23,953	417	1.7
1929.....	3	81,424	2,150	2.6
1936.....	3	12,622	1,969	15.6
1937.....	3	3,943	61	1.5
Total or average.....	—	121,942	4,597	3.8
1929.....	4	14,931	188	1.3
1930.....	4	78,938	2,873	3.6
1937.....	4	8,840	3,303	37.4
Total or average.....	—	102,709	6,364	6.2
1930.....	5	18,534	391	2.1
1931.....	5	19,356	843	4.4
Total or average.....	—	37,890	1,234	3.3
1931.....	6	2,168	101	4.7
1932.....	6	30,816	8,263	26.8
Total or average.....	—	32,984	8,364	25.4
1932.....	7	2,560	13	0.5
1933.....	7	3,858	986	25.6
Total or average.....	—	6,418	999	15.6
1934.....	8	8,538	2,693	31.5
1931.....	9	7,336	2,084	28.4
1935.....	9	21,596	8,958	41.5
Total or average.....	—	28,932	11,042	38.2

\*Estimate made of lines completely sterile.

TABLE I.—*Concluded.*

Year	No. of years selfed	Flowers observed		Percentage fertile
		Total	Fertile	
1932.....	10	16,944	9,342	55.1
1936.....	10	7,555	3,042	39.4
Total or average.....	—	24,499	12,384	50.5
1933.....	11	284	66	23.3
1937.....	11	21,028	9,941	47.3
Total or average.....	—	21,312	10,007	47.0

In Table 2 each selection is considered a line. The frequency distribution of fertility percentage after different years of selfing is shown. Over a period of 11 years the total number of lines studied is 1,216. Even though selection for high fertility was practiced each year, the average fertility count for the first five years did not exceed 6½%. The sixth year the average was raised to 25.4%. The seventh year it dropped to 15.6%, but in the following years it moved slowly upwards until approximately 50% was reached in the tenth and eleventh years. The distribution continues wide throughout the last six years of selective inbreeding. The drop back to the low percent-

TABLE 2.—*Distribution of fertility in lines of rye after different years of selfing.*

No. of years selfed	Fertility classes in percentage and number of lines in each class											Total lines	Average percentage fertile
	0 to 0.9	0.1 to 9.9	10.0 to 19.9	20.0 to 29.9	30.0 to 39.9	40.0 to 49.9	50.0 to 59.9	60.0 to 69.9	70.0 to 79.9	80.0 to 89.9	90.0 to 99.9		
1	242*	152	22	5	3	2	—	—	—	—	—	425	4.0
2	6	179	10	5	2	—	1	—	—	—	1	204	3.7
3	37	171	8	3	1	—	1	2	2	1	—	226	3.8
4	2	100	5	2	3	3	7	4	—	1	—	127	6.2
5	—	67	1	2	—	—	1	—	—	—	—	71	3.3
6	—	12	4	5	4	4	4	—	—	—	—	33	25.4
7	—	4	3	7	2	3	3	—	—	—	—	22	15.6
8	—	1	2	3	3	—	3	1	—	—	—	13	31.5
9	—	3	4	7	11	3	1	1	—	—	—	30	38.2
10	1	2	5	1	7	12	10	8	2	1	—	49	50.5
11	—	2	1	2	2	3	5	1	—	—	—	16	47.0

\*Estimated 1934-3

ages of fertility in the tenth year of selfing is due almost entirely to the behavior of (S) 26, one of the original lines. In the selections from this line are found one 0, two in the 0.1 to 9.9, and four in the 10.0 to 19.9 classes. This line, only mediocre in fertility, has been

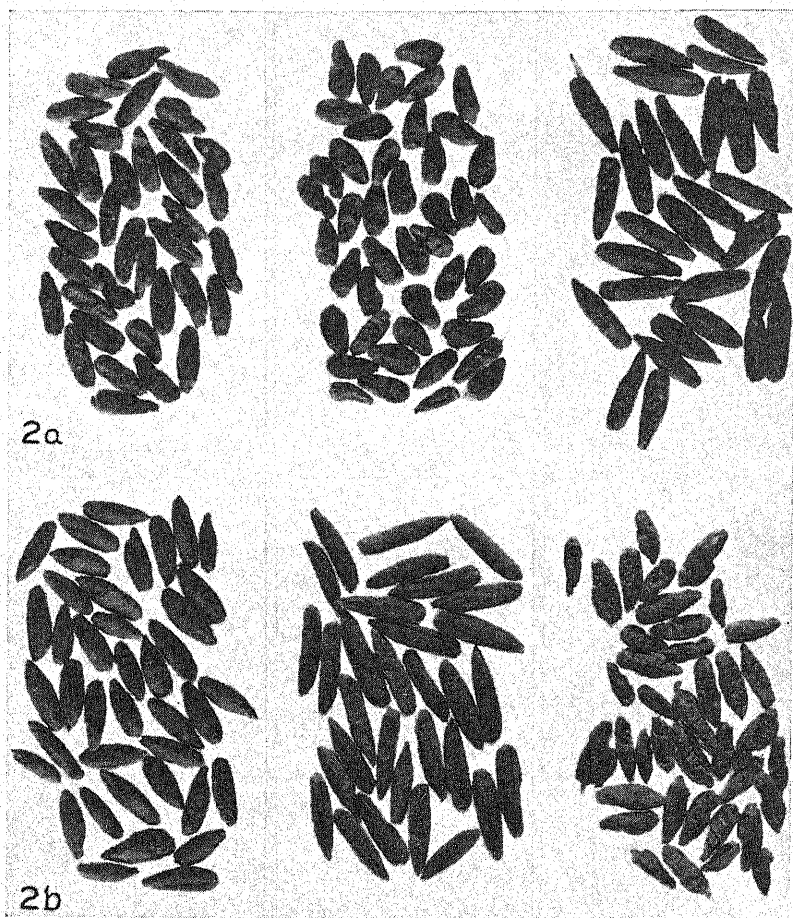


FIG. 2.—Kernels of open-pollinated and inbred rye grown in 1936. (A) 10-year inbreds; left and center groups are sister selections; right, large kernalled inbred. (B) Open-pollinated Imperial rye left; selfed hybrid second generation with large uniform kernels; and right, selfed hybrid fourth generation with poor kernel type.

carried forward because of its ability to make desirable combinations with other selections.

In Table 3 are given the number of original selections in the Schlansted parentage and the number remaining after different lengths of time after selfing. Included in this table is the number of new Schlansted selections introduced into the inbreeding program in 1926, 1927,

1934, 1935, and 1936. Nine of the 260 original selections of 1926 remained in 1927, four in 1928, and by 1933 these remaining lines had

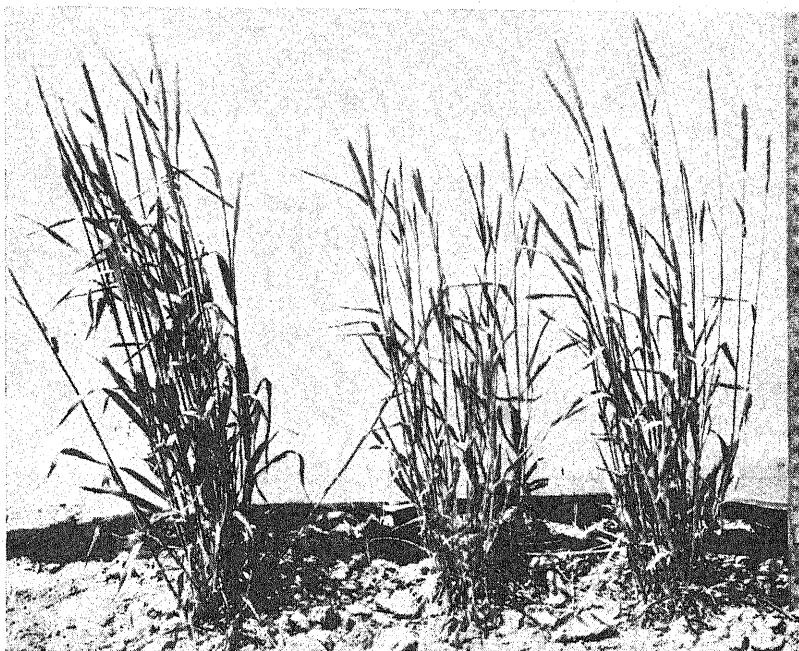


FIG. 3.—Comparison of open-pollinated Imperial rye (left) with two 7-year inbred strains center and right, grown in 1934.

TABLE 3.—*Number of original selections of Schlansted parentage and surviving lines as inbreeding and selection progressed.*

	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937
Original selections made in 1926...	260	—	—	—	—	—	—	—	—	—	—	—
Lines remaining...	—	9	4	2	2	1	1	0	—	—	—	—
Original selections made in 1927...	—	48	—	—	—	—	—	—	—	—	—	—
Lines remaining...	—	—	28	17	12	7	3	3	3	3	3	3
Original selections made in 1934*...	—	—	—	—	—	—	—	—	43	—	—	—
Lines remaining...	—	—	—	—	—	—	—	—	—	6	6	5
Original selections made in 1935*...	—	—	—	—	—	—	—	—	—	36	—	—
Lines remaining...	—	—	—	—	—	—	—	—	—	—	2	2
Original selections made in 1936...	—	—	—	—	—	—	—	—	—	—	24	—
Lines remaining...	—	—	—	—	—	—	—	—	—	—	—	6

\*Estimate of lines completely sterile.

been dropped because of low fertility. In 1927, 48 selections were again made of the Schlansted, 3 of which are being continued. Even though only three of the original lines are now represented, the 12 reselected progenies from these three lines show 21,028 flowers in 1937, the eleventh year of selection. New introductions of 43 lines in 1934, 36 in 1935, and 24 in 1936 were made from the Imperial which is a selection from the Schlansted. In each case, as was true of the first two years' introductions, the greatest number of lines drop out in the first year of selection due to the fact that there is a marked drop in surviving lines when inbreeding is followed by selection of the highly fertile and vigorous lines.

#### PRELIMINARY STUDIES OF HYBRIDS OF INBRED LINES

Preliminary studies of hybrids from inbreds were made in 1931, 1932, 1933, and 1934. In 1931 four inbred selections of the Schlansted, Wis. Ped. 2, were crossed. Only two of the  $F_1$  progenies showed hybrid vigor equaling or better than the open-pollinated. In 1932 several crosses were made between inbreds of the Abruzzes and the inbreds of Pedigree 2. Some of the  $F_1$  selections were inferior and some were superior to the open-pollinated rye. In this experiment selection was focused on the superior lines. Further inbreeding of these more highly fertile hybrid lines should determine whether progress can be made through selection of hybrids.

Table 4 gives the number of flowers observed, the number fertile, and the percentage fertility in rye hybrids selfed and continuously selected from one to five years. Certain hybrids are of Abruzzes, others are of Schlansted, and others are a cross between Abruzzes and Schlansted. The hybrids from Abruzzes were made at the Indiana Experiment Station and appear for the first time in this table in 1931 as second year inbreds. Beginning with 1933 new crosses were made each year from the selected inbred lines of the Imperial which were inbred and selected in the years following.

Because the parentage of the lines given in Table 4 differ, general deductions cannot be made on the trend of fertility in the later years of selection. The fourth and fifth year fertility percentages of inbred selections may be reduced by the Abruzzes parentage, which is a southern rye not well adapted to Wisconsin conditions. The average percentage of fertility in the first and second years of selfing and selection in all hybrids is practically the same as that of the tenth and eleventh years' averages of the selected inbreds (Table 1). More work on selection within inbreds of hybrids will be necessary to determine the possibilities of rye improvement along these lines.

Table 5 shows the distribution of fertility in the selections of inbreds from hybrids over a five-year period which is much the same as that of the last four years of inbreeding as shown in Table 2. More years of study on a greater number of lines of wider germ plasm ranges will be necessary to determine whether any advantage is to be gained by inbreeding hybrids in rye.

TABLE 4.—*Summary of fertility percentage in selfed selections from rye hybrids undergoing continuous selection for fertility.*

Year	No. of years selfed*	Flowers observed		Percentage fertile
		Total	Fertile	
1933 c†.....	1	7,696	2,869	37.3
1934 b.....	1	4,020	1,983	49.3
1935 b.....	1	10,168	3,155	31.0
1936 b.....	1	8,336	5,146	61.7
1937 b.....	1	17,444	9,399	53.8
Total or average.....		47,664	22,552	47.3
1931 a.....	2	10,850	5,328	49.1
1934 c.....	2	36,037	12,413	34.4
1935 b.....	2	2,414	1,128	46.7
1936 b.....	2	10,436	5,432	52.1
1937 b.....	2	8,528	5,496	64.5
Total or average.....		68,265	29,797	43.6
1932 a.....	3	8,576	3,065	35.7
1935 c.....	3	8,339	2,967	35.6
1936 b.....	3	3,678	981	26.7
1937 b.....	3	9,454	4,158	44.0
Total or average.....		30,047	11,171	37.2
1933 a.....	4	1,038	401	38.6
1936 c.....	4	11,650	5,235	45.5
Total or average.....		12,688	5,636	44.4
1934 a.....	5	2,094	338	16.1
1937 c.....	5	6,844	2,228	32.6
Total or average.....		8,938	2,665	28.7

\*Filial generation number.

†a = Hybrids of Abruzzes; b = Hybrids of Schlansted; c = Hybrids of Abruzzes and Schlansted.

## DISCUSSION

This line of investigation on rye fertility was started with the purpose in mind of producing a highly fertile rye by selection of better inbreds and by crossing these lines of high fertility. Owing to the large amount of material which may be produced from year to year, only those lines showing promise of superiority could be retained for further selection. The fertility of a large number of flowers was observed and numerous lines were obtained, but as selection progressed the number of lines was reduced to a comparatively few. This has been a serious limitation in securing parent stocks for hybridizing.



TABLE 5.—*Distribution of fertility in hybrid lines of rye after different years of selfing*

No. of years selfed	Fertility classes in percentage and number of lines in each class											Total no. of lines	Average percent-age fertile
	0 to .09	0.1 9.9	10.0 19.9	20.0 29.9	30.0 39.9	40.0 49.9	50.0 59.9	60.0 69.9	70.0 79.9	80.0 89.9	90.0 99.9		
1	2	13	6	6	12	11	24	19	21	5	2	121	47.3
2	—	3	6	14	14	17	18	22	13	4	3	114	43.6
3	—	8	4	4	13	7	14	2	4	3	1	50	37.2
4	—	—	5	6	5	11	13	5	2	—	—	47	44.4
5	—	5	5	2	4	5	2	1	—	—	—	25	28.7

Bagging heads doubtless disturbs the environmental conditions favorable to seed setting for the plant. Reduced air circulation and lack of sunlight and increased temperature and humidity which occurs under bags, will probably serve to reduce fertility. While comparative data are not available, fertility of 30 to 60% under bags of selected inbreds may be comparable to the fertility of open-pollinated stocks. Brewbaker (1) suggests that bagging increased barrenness in Marquis, Mindum, and Emmer wheats, which are normally self-pollinated. Seasonal conditions probably affect the amount of fertility.

The problem of increasing and maintaining fertility in inbreds is somewhat different from that of hybrids. Evidently progress has been made in increasing fertility of inbred lines. Whether continued selection is necessary to keep up the fertility has not yet been answered by this work. Selection within inbreds of hybrids has not increased and probably has not maintained the fertility found in the early generations following hybridization.

Selection of certain inbred lines within hybrids may be necessary to stabilize seed setting ability. Variation in seed setting of different lines has occurred in selfed lines of hybrid origin. First year inbreds of hybrid stocks in 1937 show four lines to be consistently high in fertility and three lines to be variable. A similar condition existed in the 1936 one-year inbreds of hybrids; eight lines are high in fertility and apparently stable, while only two lines are low. The high fertility one-year inbred lines in 1936, which were carried over into 1937 as two-year inbreds, were all high in fertility, carrying about the same average percentage as the previous year.

The possibility of stabilizing high fertility in inbreds originating from hybrids is undetermined so far as this investigation is concerned. The percentage fertility has decreased with continued inbreeding (4 to 5 years) in the limited stocks available from Abruzzes crosses or hybrid combinations of Abruzzes and Schlansted inbreds. Inbreds of less duration (2 to 3 years) from Imperial stock have provided some hope that it will be possible to stabilize high seed setting ability in certain lines.



It might be said that the highly fertile lines selected each year were heterozygous, but this would hardly seem to be the case where several different lines showed no high and low segregates in the second year, with the general average percentage approximately the same as that of the year previous.

The work with inbreds from hybrid origin has of necessity been limited in scope and the full range of possibilities may not have been realized. However, the work is being continued in inbreeding from additional open-pollinated varieties. Each season for the past five years some open-pollinated stocks have been inbred so as to broaden the scope and foundation for investigation of inbreeding and hybridization. It will soon be possible to combine the recently purified inbreds with both the long-time inbreds and inbreds that have been partially reduced to homozygosity after hybridization. Even though some hybrids have been disappointing in their performance in the limited amount of second cycle inbreeding, this source of material may become very valuable as stocks for combining in hybrids. Winter-hardy varieties when inbred may influence the outcome of hybridization in a different and more acceptable way than the nonhardy Abruzzes stock. Continued efforts in producing and maintaining inbred lines of a greater range of germ plasm will serve in the future for determining just how much progress may be made in discovering fundamental principles of rye breeding and in determining how best these principles may be applied in rye improvement.

Isolation of different inbred lines and hybrids from stocks on hand thus far have not proved successful in establishing a variety of rye that is as good a producer as Imperial. It must be kept in mind that this variety was in the first place produced by narrowing certain lines and then compositing them. This variety has been consistently the highest yielder at the Experimental Farm and therefore provides a high standard to be surpassed in the breeding program. Compositing several inbred lines may offer desirable means of obtaining a synthetic variety that will have good quality and high production.

Even though the work thus far has not been successful in producing a variety that is equal in qualities to commercial varieties, certain possibilities are still evident. With increased number and types of inbred stocks, there likely will be additional principles to be discovered in rye breeding. The application of some of these principles may lead to a superior open-pollinated rye.

#### SUMMARY

Vigor in vegetative growth is usually less in the inbreds than in the open-pollinated rye. Many undesirable segregates appeared by inbreeding which were eliminated. After ten years of inbreeding, some lines still show segregation for size and shape of kernel.

Fertility in inbred lines has been increased by selection. In the first five years of inbreeding and selection the fertility average was low, not exceeding  $6\frac{1}{2}\%$ . The last four years it was higher, reaching approximately  $50\%$ . The percentage of fertility was distributed widely each year, with greater frequency in the low fertility classes in the early years of inbreeding.

Some crosses showed hybrid vigor and were superior to open-pollinated rye, while others were so inferior that they were discontinued.

The average fertility of the first and second year's selfing and selection of hybrids compares closely with that of the tenth and eleventh years' inbreds. The range of fertility distribution of selected inbreds from hybrids is wide, differing little from that of the last four years' selection of inbreds.

Further experimental work along these lines is necessary to determine the possibility of obtaining inbred selections or hybrid combinations as productive as the best open-pollinated varieties of rye now being grown.

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## SEPARATING A GENERALIZED INTERACTION INTO COMPONENTS<sup>1</sup>

W. B. KEMP<sup>2</sup>

BREEDERS are frequently confronted by the need for determining both relative yield and differential responses or interactions of selected strains or varieties of plants. A determination of differential response is desirable (a) for use in determining the significance of differences in yield, (b) for classifying the strains in separate response groups, and (c) as a starting point from which studies may be undertaken to determine the causes for these differences in behavior. The procedures presented here for breaking down interactions are of much assistance in analysis of complex relationships. However, the number of components which are isolated is beyond the number of sets of degrees of freedom available for a determination of their significance. Therefore, it is usually desirable to group similar components before rendering final judgments for those cases in which such minute analysis is desirable in preliminary studies.

Analysis of variance (1)<sup>3</sup> is now an indispensable tool for use in determining significance of differences in yield and seasonal response among varieties and strains of plants. Its use is justified in most cases where one may logically assume that a homogeneous error is common to the observations of all classes. The data are very easily analyzed when observations of similar classes occur with equal frequency. This method of statistical analysis is of particular value when the number of degrees of freedom is great enough to permit isolation of differential responses, such as interactions between variety and season, in addition to "residual error".

When observations of different classes do not occur with equal frequency the data are more difficult to analyze. However, Yates (2, 3) and Snedecor and Cox (4) have presented procedures for dealing with these cases of unequal frequency.

### INTERACTION

Such yield interactions as those between variety and rate of planting apparently were observed early in agronomic investigational work. Mooers (5) pointed out definite corn yield interactions between variety and soil fertility. A statistical consideration of this phenomenon was presented by Fisher and Mackenzie (6) in studies of differential response of potato varieties to manurial treatments. Engledow and Yule (7) stressed the necessity for forming some estimate of the extent to which weather conditions may influence relative yields.

It was pointed out by Maskell (8) that variance introduced by variety differences is of importance in establishing general superiority

<sup>1</sup>Contribution from the Department of Genetics and Statistics, University of Maryland, College Park, Md. Also presented at the annual meeting of the Society held in Chicago, Ill., December 3, 1937. Received for publication February 14, 1938.

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<sup>3</sup>Figures in parenthesis refer to "Literature Cited", p. 424.

of one variety over another only when such variance is significantly larger than that introduced by interactions between variety and environment. Even for such generalizations to be valid, the investigation must have sampled various environmental conditions. The attitude presented by Maskell has received general approval and these lower order interactions, when they are considered to be significant, are used as the source of error by which generalized significance of variety differences in mean yield is determined.

It is logical to use a homogeneous interaction with variety as an estimate of error in determining the general significance of variety differences. However, its very nature is such that one may suspect heterogeneity in any significant interaction in an analysis that involves more than two varieties or strains. Therefore, it follows that any interaction may logically be used as an estimate of error only after it has been analyzed into relatively homogeneous components. Each of these components is a logical error for the determination of general significance of differences for those varieties only which contribute to it.

Wheat varieties on test at the Maryland Experiment Station tend to fall into distinct response groups (9). Significant variety-season interactions exist only when wheats of different response groups are included in one analysis.

#### SEPARATING COMPONENTS OF A HETEROGENEOUS INTERACTION

A procedure by which the significance of the contribution associated with each degree of freedom for interaction is determined separately by use of the "t" test has been presented by Immer, *et al.* (10). The problem under discussion here is an evaluation of differential response of two strains within an analysis when more than one degree of freedom is available for a determination of this response. The "t" test is not designed for such an evaluation. Therefore, analysis is carried out in such a way that Snedecor's "F" test may be used.

In Table 1 yields are presented, in bushels per acre, of duplicate plats of four wheat varieties (M, T, C, and B) during a 15-year period. For simplicity, yields are presented at the nearest even bushel. Table 2 shows results obtained by ordinary analysis of variance of these data. The effects of season, variety, and the interaction of season with variety may all be judged significant in size when compared with residual error. However, the contribution due to variety differences is not significantly greater than that due to interaction. Therefore, one might draw the preliminary conclusion that with such great differential responses among these varieties, no one can be judged generally superior to any other. A necessity for modifying this preliminary judgment becomes apparent when yields for variety C are excluded from Table 1 and the remaining figures are subjected to analysis of variance. Then the contribution due to interaction is reduced to insignificance, while the contribution due to variety may be judged significant when compared with this reduced interaction. Obviously, the presence of C has affected in no way true relationships between M, T,

TABLE 1.—Data from which components of interaction and variety difference are isolated.

Year	Yields of wheat, bushels per acre, on duplicate plats of four varieties (M, T, C, and B)												
	M <sub>1</sub>	M <sub>2</sub>	T <sub>1</sub>	T <sub>2</sub>	C <sub>1</sub>	C <sub>2</sub>	B <sub>1</sub>	B <sub>2</sub>	S <sub>M</sub>	S <sub>T</sub>	S <sub>C</sub>	S <sub>B</sub>	S
1919.....	24	26	21	24	18	22	20	26	50	45	40	46	181
1920.....	32	31	27	29	28	31	28	29	63	56	59	57	235
1921.....	21	24	21	19	13	12	22	23	45	40	25	45	155
1922.....	24	20	25	26	25	24	23	28	44	51	49	51	195
1923.....	38	34	31	32	35	33	35	33	72	63	68	68	271
1924.....	30	31	31	32	34	37	36	30	61	63	71	66	261
1925.....	37	36	32	31	40	42	30	35	73	63	82	65	283
1926.....	38	46	46	43	47	50	41	45	84	89	97	86	356
1927.....	24	19	16	28	27	31	21	23	43	39	58	44	184
1928.....	36	33	31	32	40	33	32	36	69	63	73	68	273
1929.....	34	34	33	33	31	29	36	38	68	66	60	74	268
1930.....	43	41	43	42	45	45	38	47	84	85	90	85	344
1931.....	42	42	30	33	41	43	34	38	84	63	84	72	303
1932.....	22	21	24	23	20	18	23	22	43	47	38	45	173
1933.....	26	23	20	20	24	25	24	23	49	40	49	47	185
S.....	471	461	431	442	468	475	443	476	932	873	943	919	3,667

TABLE 2.—Analysis of variance of the data in Table 1.

Source	Freedom	Sum of squares	S <sup>2</sup>
Total.....	119	8179.604	
Season.....	14	7058.979	504.21
Variety.....	3	94.704	31.57
SV interaction.....	42	701.421	16.70
Residual error.....	60	324.5	5.41

and B. However, its removal from the analysis has served to reverse the judgment relative to these remaining varieties. Therefore, the immediate problem is a determination of those particular variety comparisons which contribute significant interactions. Significances of mean yield differences are determined at the same time in order that the method which is employed may be compared with that used for the "t" test.

Figures in Table 3 are differences between total yields of the two plats for various combinations of two varieties each. Thus 5, for M-T for 1919, is the difference between 24 + 26, or 50 for M, and 21 + 24, or 45 for T, in that year. Among four varieties are six such sets of differences, i. e.,  $\frac{4(3)}{2(1)} = 6$ .

For isolating interaction between M and T in Table 3, one obtains 720.93 as the sum of the squares of deviations of M-T from the corresponding mean, and divides by 2 times 2 times 2 times 7, or 56. The first 2 results from the fact that differences between two values are used. The second 2 is used because the figures are the sums of two plats per year. The third 2 results from six combinations among which each variety is included three times. The 7 is one-sixth of 42 degrees

TABLE 3.—*Isolating components of variety difference and interaction with season*

Year	M — T	M — C	M — B	T — C	T — B	C — B
1919.....	5	10	4	5	— 1	— 6
1920.....	7	4	6	— 3	— 1	2
1921.....	5	20	0	15	— 5	— 20
1922.....	— 7	— 5	— 7	2	0	— 2
1923.....	9	4	4	— 5	— 5	0
1924.....	— 2	— 10	— 5	— 8	— 3	5
1925.....	10	— 9	8	— 19	— 2	17
1926.....	— 5	— 13	— 2	— 8	3	11
1927.....	4	— 15	— 1	— 19	— 5	14
1928.....	6	— 4	1	— 10	— 5	5
1929.....	2	8	— 6	6	— 8	— 14
1930.....	— 1	— 6	— 1	— 5	0	5
1931.....	21	0	12	— 21	— 9	12
1932.....	— 4	5	— 2	9	2	— 7
1933.....	9	0	2	— 9	— 7	2
Total.....	59	— 11	13	— 70	— 46	24
S (X — $\bar{X}$ ) <sup>2</sup> .....	720.93	1,264.93	389.73	1,575.33	180.94	1,479.60

One component of  $s^2$  for variety,  $M - T = \frac{59^2}{*60} = 58.02$

One component of  $s^2$  for interaction,  $M - T = \frac{720.93}{**56} = 12.88$

\*15 = number per column  
1 = columns.  
2 = differences of two  
2 = sums of two plats per year

\*\*7 = one sixth of 42 degrees of freedom  
2 = differences of two  
2 = sums of two plats per year  
2 = six combinations including each variety three times

of freedom. The result, 12.88, is the contribution of differences between M and T to interaction. Table 4 shows the six contributions to interaction which trace to the six columns of differences. Their average, 16.70, is the same as that obtained by ordinary analysis of variance in Table 2.

TABLE 4.—*Separate components of  $s^2$  for error, for variety, and for season as isolated from Table 3.*

Component	Error	Component	Variety difference	Interaction
M.....	5.33	M, T	58.02	12.88
T.....	3.03	M, B	2.82	6.96
C.....	4.37	T, B	35.27	3.23
B.....	8.90	M, C	2.02	22.59
	—	T, C	81.67	28.13
	—	B, C	9.60	26.42
Average....	5.41	....	31.57	16.70

As an evidence that the individual components of interaction, like those of variety difference, constitute a heterogeneous set, the individual components of residual error are presented for comparison. Relatively small differences exist among these components because they constitute a homogeneous set.

For a determination of the significance of any one component of interaction found in Table 4, one looks up  $F$  for  $N$  of 30 and 14 in the .05 table. The interpolated value is approximately 2.03. The product of 5.41 and 2.03 is 10.98. Therefore, any component of interaction as large as 10.98 may be considered significant.

The algebraic sum of 15 differences between  $M$  and  $T$  for the 15 years is 59 (Table 3). In order to determine significance of such a sum of differences, look up  $F$  for 14 and 1 degrees of freedom. Its value in the .05 table is 4.6. Since 12.88 times 4.6 is 59.25, it follows that the contribution to  $s^2$ , for variety, as great as 59.25 may be judged significant.

To find the component of  $s^2$  for variety which is contributed by a difference of 59 between  $M$  and  $T$ , it is necessary to divide 59<sup>2</sup> by 15 times 1 times 2 times 2. The result is 58.02 which is not quite as large as the 59.25 necessary for significance on the basis of a .05 table. These divisor numbers result from the facts that the number per column is 15, the number of columns is 1, each difference in the column is between 2 values, and the number of plat yields added for each sum before differences are obtained is 2.

Table 4 shows the  $s^2$  for variety difference which traces to each of the six sets of differences. Their average is 31.57, the same value which is obtained from normal analysis of variance in Table 2.

Fourteen degrees of freedom for interaction, or one-third of the total of 42, are available for three of six components because there are only three degrees of freedom for variety. That is, if three of the differences for any one year are chosen judiciously, the remaining three are fixed.

An examination of the sets of figures in Table 4 shows that  $T$  is clearly lower in yield than  $M$ ,  $B$ , or  $C$ . From figures in the same table it may be observed that significance of interaction results chiefly from the fact that  $C$  responds to seasons in a way clearly different from the responses of  $M$ ,  $T$ , or  $B$ . An examination of the figures in Table 3 shows that interaction between  $M$  and  $T$  rises to a significant value because of the marked difference in yield in the year 1931 only. Hence, for the present discussion the significance of this value is ignored. In any case its significance is inconsistent with the ( $M$ ,  $B$ ) and ( $T$ ,  $B$ ) interactions. Varieties  $M$ ,  $T$ , and  $B$  belong to one response group, while  $C$  belongs to another. The generalized variety season interaction of 16.70 to which  $C$  makes the major contribution is not a valid estimate of error for testing  $M$ ,  $T$ , and  $B$ . It would seem reasonable to use the average of 12.88, 6.96, and 3.23, or 7.69, as the variety-season interaction of  $M$ ,  $T$ , and  $B$  involving two degrees of freedom, while the corresponding interaction between  $C$  and this group would account for the uniformly large values of 22.59, 28.13 and 26.42 involving 1 degree of freedom. On separating interaction in this way, 7.69 is judged insignificant between  $M$ ,  $T$ , and  $B$ . Therefore, the observed superiority of  $M$  and  $B$  over  $T$  can be assumed to apply generally. On the other hand, the even greater superiority of  $C$  over  $T$  can be considered as valid for the conditions of the test only because of the very large interaction of 25.71 with which it might be compared for general validity.

## CONCLUSION

Briefly, the foregoing extension of analysis of variance offers an opportunity to study the contributions of different variety comparisons to both yield difference and to interaction.

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## COST OF BINDWEED ERADICATION BY THE TILLAGE METHOD<sup>1</sup>

J. V. SRB, L. S. EVANS, and F. D. KEIM<sup>2</sup>

IT has been definitely established that field bindweed (*Convolvulus arvensis* L.) can be eradicated by clean cultivation under Nebraska conditions. Information on the cost of this method is meager, however. It is the purpose of this paper to present an analysis of the cost data of actual eradication operations conducted on a field-size scale in two Nebraska counties, Lancaster and York, during the period 1935 to 1937. Since the two investigations differed as to time and locality separate accounts will be given.

### TESTS IN LANCASTER COUNTY

The studies in Lancaster County were made in seven fields in 1935 and 1936. The soils were of the Waukesha and Wabash series, ranging from silt loam to clay loam. All fields were summer tilled for two years. They varied in area from 1.5 to 6.1 acres. Their initial infestation with bindweed varied from medium to heavy and had been established for not less than five years.

In preparation of the fields for cultivation, all rubbish and excess plant growth were removed or burned and where necessary the fields were plowed. The cost of original plowing was excluded from all computations in the Lancaster County fields. In the tillage operations a 10-20 tractor, a duckfoot cultivator of 7½ feet width, and a student operator were employed. The duckfoot cultivator was run at a depth of 3 to 4 inches and at intervals when the plants had made a growth of 4 or 5 inches.

The extent of growth permitted following the emergence of plants was based on the findings of Kiesselbach, Petersen, and Burr.<sup>3</sup> As early as 1924, these workers found that the number of necessary tillage operations could be reduced by permitting slight growth of the plants. Frequent tests were made to see that all plants were severed below ground. Sharp and liberally over-lapping shovels were found effective in preventing the survival of any of the shoots following each tillage.

Accurate and complete records were kept on all operations and results connected with the eradication process. The percentage of reduction of the infestation on the fields was not based on actual counts but on visual estimates, because numbers or counts do not

<sup>1</sup>Contribution from the Department of Agronomy, Nebraska Agricultural Experiment Station, and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, cooperating, Lincoln, Nebr. Printed with approval of the Director as Paper No. 207 Journal Series. Received for publication February 14, 1938.

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<sup>3</sup>KIESELBACH, T. A., PETERSEN, N. F., and BURR, W. W. Bindweeds and their control. Nebr. Agr. Exp. Sta. Bul. 287. 1934.

always indicate the vigor of plants nor do they adequately measure the effectiveness of a treatment. This viewpoint is in accord with that of Crafts.<sup>4</sup>

To arrive at the cost of tillage per acre, the expense of operating per hour was first established. Table 1 presents data showing the cost of farm implements and their operation reduced to an hour basis. This includes fuel, oil, interest on investment, depreciation, repairs, and operator's wages. The total cost of operating the equipment was \$0.70 per hour. The equipment used according to the duty of the machines should have averaged 2.3 acres per hour. Table 2, which records in detail the work done on the seven fields, shows an average of 2.05 acres actually cultivated per hour. The cost of cultivation per acre on these same fields was \$0.34. No allowance is made for traveling to and from the fields.

TABLE 1.—*Data showing the cost of farm implements and their operation in Lancaster County, Nebraska, reduced to an hour basis, 1935-36.*

Item	Cost per hour
TRACTOR: Cost \$960.00	
Expense of operating tractor:	
Fuel, 9c per gal. ....	\$0.171
Oil, 20c per qt. ....	0.0765
Interest, basis of 1,300 hours yearly operation	0.044
Depreciation, basis of 1,300 hours yearly operation (\$96.00 year) .....	0.074
Repairs, basis of 1,300 hours yearly operation (\$40.00 year) .....	0.034
Operator's time. ....	0.250
Total cost. ....	\$0.6495
CULTIVATOR: Duckfoot, sweep of 7½ feet Cost \$86.05	
Expense of operating cultivator:	
Interest, Basis of 1,300 hours yearly operation....	\$0.039
Depreciation, Basis of 1,300 hours yearly operation....	0.0044
Repairs, \$10.00. ....	0.0077
Total cost. ....	0.0511
TOTAL COST:	
Tractor per hour .....	\$0.6495
Cultivator per hour .....	0.0511
Grand total per hour. ....	\$0.7006

As shown in Table 2 the infestation on the seven fields was reduced 98 to 100% by the two years of clean cultivation. When a reduction of more than 98% was reached on any field it was considered machine-through. The few remaining plants were treated with sodium chlorate or were hoed. The total cost of spraying 100 plants with sodium chlorate in this follow-up treatment was found to be \$0.29.

<sup>4</sup>CRAFTS, A. S. Factors influencing the effectiveness of sodium chlorate as a herbicide. *Hilgardia*, 9:1935.

TABLE 2.—*Cost of clean tillage for the bindweed control of seven fields in Lancaster County, Nebraska, 1935-36.*

Field No.	Area acres	Date of plowing, 1935	Cultivations		Calculations on an acre basis			Infestation	
			First year, 1935	Second year, 1936	Cultivations per hour	Cost single cultivation per acre	Total cost per acre	Original	Reduction in two years, %*
1.....	1.5	June 14	10	1	2.02	\$0.35	\$3.80	Spotted	100
2.....	3.5	June 17	12	10	2.04	0.34	7.57	Heavy	99
3.....	3.5	June 15	14	14	2.11	0.33	9.32	Heavy	99
4.....	6.1	June 26	12	9	2.17	0.33	6.84	Spotted	99+
5.....	1.5	July 1	10	5	2.09	0.34	5.04	Medium	99+
6.....	1.5	July 16	11	11	2.14	0.33	7.19	Medium	99
7.....	5.6	June 27	10	14	1.78	0.39	9.43	Heavy	98
Average	3.3	—	11	9	2.05	0.34	7.03	—	—

\*Based on stand of May 20, 1937.

It is interesting to note in Table 2 the variation in number of cultivations required in different fields during the second year and the difference in cost of eradication. The lowest cost occurred in field No. 1 amounting to \$3.80 per acre and the highest in field No. 7 with \$9.43.

#### TESTS IN YORK COUNTY

The study made in York County in 1936 and 1937 was on a gently rolling field of approximately 39 acres of the Hastings silt loam series. The field was almost solidly infested with field bindweed when clean tillage was begun April 29, 1936, by plowing the field to a depth of 7 inches. Corn stalks were removed by raking and burning before the land was plowed. Cultivations were made thereafter to a depth of 4 inches with a duckfoot cultivator 8½ feet in width equipped with 10- and 12-inch shovels which allowed an overlap of 2 or 3 inches. This lap was important because it prevented plants from slipping through and remaining unsevered. The plants were allowed to make three to four days growth above ground between cultivations.

The field was blank-listed at the end of the first season to reduce soil blowing. The first plants emerged the following spring about April 21 and the lister ridges were thrown in at that time with a "go-dig" and the duckfoot cultivator was used during the remainder of the season until September 16, 1937, when the field was seeded to wheat. It was estimated at that time that 5% of the original stand of bindweeds remained. The field will be cultivated after wheat harvest in 1938 in an attempt to destroy the remaining plants.

Table 3 shows that the mean cost of a single cultivation per acre was \$0.32 in 1936 and \$0.34 in 1937. The total cost of 32 cultivations over the two-year period was \$10.34 per acre. These cost figures include the original plowing and the blank-listing in the fall of 1936

and throwing in the ridges in the spring of 1937 in preparation for the use of the duckfoot cultivator. They also include the operator's time valued at 25 cents an hour. Depreciation on the tractor and cultivator are also included, but since the tractor was used in operating the remainder of the farm, it was arbitrarily agreed that interest on the investment and taxes would not be charged against this tillage.

TABLE 3.—*Showing the average cost per acre of clean cultivation on the 39-acre field in York County, Nebraska, 1936-37.\**

Item	1936	1937	Total
Number of cultivations†. . . . .	20	12	32
Acres cultivated. . . . .	772	463	1,235
Acres per hour. . . . .	1.91	2.20	
Operating expenses (fuel, oil, repairs). . . . .	\$2.14	\$1.14	\$3.28
Depreciation on machinery. . . . .	1.54	1.55	3.09
Labor (25c per hour). . . . .	2.62	1.35	3.94
Total cost per acre. . . . .	6.30	4.04	10.34
Cost per cultivation per acre. . . . .	0.32	0.34	0.32

\*Figures include original plowing, blank-listing, and throwing in lister ridges.

†Average interval between cultivations was 10 days in 1936 and 13 days in 1937.

## DISCUSSION

### COST IN TWO LOCALITIES COMPARED

In York County the average cost per cultivation per acre was \$0.32 over the two-year period as compared with \$0.34 for the seven fields in Lancaster County. This difference may be due in part to the larger equipment and the larger field in York County which permitted greater economy in each operation.

Despite the fact that the experiments were conducted under dissimilar conditions, the cost per cultivation per acre is in reasonably close agreement in the two studies. The difference in cost of cultivation suggests that by an increase in size of equipment the cost per cultivation may be somewhat reduced.

Additional factors which may affect the output per hour and therefore the total cost of cultivation are soil structure, skill of operator, amount of organic matter in soil, and the amount of trash or plant residues present on the surface.

Because of lack of suitable equipment the fields were not cultivated until after June 15, 1935, in Lancaster County. It was not determined from these experiments whether complete eradication at the end of the second year might have been effected if cultivation had begun as soon as the bindweed plants emerged in the spring. It is apparent, however, that this delay in starting cultivation accounted, in part at least, for the fact that the average number of cultivations was 22 over the two-year period as compared to 32 cultivations during two full seasons in York County. The data should serve, however, to calculate the mean cost of cultivation per acre.

When the work of eradication by the tillage method was started on a field in Lancaster County, the fence rows, if infested, received immediate treatment with sodium chlorate. As in the fields, weeds and rubbish were first removed. Individual plants were sprayed with a

sodium chlorate solution (1 pound of sodium chlorate to a gallon of water). The application was made with a small hand sprayer. Only a small amount of material and labor were required to clean the fence rows of bindweed.

#### PROPOSED FOLLOW-UP TREATMENTS

Individual plants remaining after about 98% of the original stand have been killed by cultivation may be treated more economically by cutting off with a hoe or by individual treatments with a small quantity of sodium chlorate than by cultivating the entire field.

Careful attention should be given to field management following eradication to prevent the re-establishment of a stand of bindweed by seed carried over in the soil or present in the fertilizer or in the crop planted. Cropping practices which include intertilled crops will aid in controlling young seedlings if they are not allowed to become well established before cultivation.

#### SUMMARY

With the standard tillage equipment used in these bindweed eradication studies the total cost per acre per cultivation ranged from 32 to 34 cents. An interval of 4 to 6 days of growth between cultivations is suggested as a means of reducing the total number of cultivations required and therefore the cost of bindweed control. Excess trash should be burned before beginning clean cultivation with a duckfoot cultivator.

Two successive years of clean cultivation eradicated 95 to 100% of the original stand of bindweed. Further supplementary treatment is necessary to complete eradication.

The average interval between cultivations in York County was 10 days the first year and 13 days the second. In Lancaster County the average interval was 8 days in 1935 and 10 days in 1936.

In York County the field received a total of 32 cultivations in 1936 and 1937. The seven fields included in the Lancaster experiment averaged 22 cultivations during the two-year period 1935-36.

It appears from these preliminary investigations that bindweed can be eradicated by the tillage method under ordinary Nebraska field conditions for approximately \$10.00 per acre.

CHARACTER ANALYSIS OF WINTER WHEAT VARIETIES<sup>1</sup>W. W. WORZELLA and G. H. CUTLER<sup>2</sup>

NEVER before was the task of the wheat breeder more exacting and difficult than it is at the present time. Today he must not only develop varieties possessing the ability to give maximum yields, but in addition he must synthesize into the same variety all or nearly all of the major characters that will render it more desirable to the locality and purposes for which it is intended. A complete knowledge, therefore, of all major varietal characters is important and necessary in a wheat-breeding program. Obviously, such a knowledge is fundamental and basic to an intelligent selection of suitable parental stock. In this paper reference will be made to soft and semi-hard wheat varieties only; however, so far as the underlying principles are concerned, they apply equally to the hard wheats.

In illustrating the procedure followed in this study an analysis is made of 11 characters of 30 varieties of soft and semi-hard winter wheats grown at Lafayette, Indiana, during the five years of 1933 to 1937, inclusive.

## MATERIALS AND METHODS

The experiments here reported were conducted on 30 varieties of wheat included in the eastern winterhardness wheat nurseries planted in cooperation with the U. S. Dept. of Agriculture Bureau of Plant Industry and interested state experiment stations. Each variety was grown under uniform soil conditions, in rod-row plats replicated four times. Numerical data on 10 major characters are reported, namely, winterhardness, yield, gluten strength, meal color, meal particle size, test weight, kernel size, leaf rust, loose smut, and plant height. Strength of straw was also studied. The data for relative winterhardness reported as percentage survival were obtained from both field determinations and artificial freezing tests. In the former, estimates were made on each of four replications, while in the latter comparable data were secured on eight separate tests in which seedlings grown in the field in flats and naturally hardened were subjected to a controlled temperature of  $-10^{\circ}$  F for 24 hours in a cold chamber.

Gluten strength was determined by means of the wheat meal fermentation time test as developed by Cutler and Worzella (2, 3, 4)<sup>3</sup>. The carotenoid pigmentation, expressed as carotene in parts per million on finely ground whole wheat meal, was determined spectrophotometrically by the method outlined by Ferrari and Bailey (6) and Ferrari (5). The particle size index was obtained by a modified procedure of the method described by Cutler and Brinson (1). By this procedure, particle size index represents the percentage of material passing through the finer or 270-mesh sieve. Accordingly, a low index indicates large particles of flour usually associated with hard wheats and a high index indicates a fine, smooth flour characteristic of soft wheats.

<sup>1</sup>Contribution from Department of Agronomy, Purdue University Agricultural Experiment Station, Lafayette, Ind. Received for publication February 18, 1938.

<sup>2</sup>Assistant in Agronomy and Assistant Chief in Agronomy, respectively.

<sup>3</sup>Figures in parenthesis refer to "Literature Cited", p. 433.

## EXPERIMENTAL

A knowledge of both the desirable and undesirable characters of a variety to be used as parental stock is basic to any systematic plant breeding program. Since many physiological characters are greatly modified by soil and climatic conditions, the potentiality of these characters must be determined for the particular locality in which their use is contemplated. The data are shown in Table 1 with the varieties arranged in the order of decreasing winterhardiness as determined by field estimates.

The varieties studied show considerable range for all characters, when grown under Indiana conditions. For example, winter survival in the field varied from 5.2 to 80.4%; yield, 2.5 to 31.2 bushels; gluten strength, 22 to 140 minutes; color or carotene, 1.92 to 4.00 p. p. m.; particle size index, 7.1 to 18.0%. All of the varieties show varying degrees of susceptibility to leaf rust and loose smut. Considerable difference is found in test weight and size of kernel. Some varieties rate low in strength of straw, while others rate very high.

It is of interest to note that the seven varieties on the upper end of the array are rather closely related to hard wheats. Of interest is the fact that, as a whole, they are not only superior in winterhardiness but also they are relatively stronger in gluten, grind coarser, and possess a higher proportion of carotenoid pigments than do the typical soft wheats. At first thought it might seem that these data support the supposition held by many plant breeders that a linkage exists between strong gluten and winterhardiness and weak gluten and non-winterhardiness. However, when we consider the locations under which these varieties were bred and the specific purposes for which they were selected, it seems to help to explain this relationship. First of all, most of these semi-hard wheats were selected under conditions where the winters are rather severe, and with the objective of producing a winterhardy wheat with strong gluten quality. On the other hand, the typical soft wheat varieties as a rule were selected for soft or weak gluten under conditions where rather mild winters prevail. Consequently, the writers believe that the relationship between winterhardiness and quality shown in the above data is the result of selecting varieties which possessed this relationship because of the conditions under which they were grown and the objectives sought, rather than linkage. Among the typical soft wheats, the data show no correlation between winterhardiness and quality.

The soft wheat varieties that are commonly grown and found satisfactory for cakes, crackers, pastry products, etc., possess a definite quality. The white wheats show the weakest gluten or a "time" of 22 to 23 minutes, while the red soft wheats vary in gluten strength from 34 to 53 minutes when grown at Lafayette. Color, or carotenoid pigmentation, varied from 1.92 to 2.87 p.p.m. in the soft wheats. Particle size index varies from 11.2 to 18.0% in the soft varieties, with the majority over 12.5. Since little information is available on quality in soft wheats, it appears that the above data on the various components of quality may be used as a guide in breeding new wheats that are to be used for the same purposes. Milling and baking tests on these varieties are underway in a further study of quality in soft wheats.

TABLE 1.—Data for 11 characters of 30 varieties of soft and semi-hard winter wheat grown at Lafayette, Indiana, during the 5 years 1933 to 1937.

Variety	Winter-hardiness, % survival		Yield, bu. per acre	Quality				Disease		Height, in.	Strength of straw
	Field tests	Artificial tests		Gluten time test, min.	Color, in p.p.m.	Particle size index %	Test weight, lbs.	1,000 kernel weight, grams	Leaf rust %	Loose smut†	
Minhardi.....	80.4	76.6	23.1	68	3.89	11.9	55.9	21.2	47.0	1.4	Good
Purkof.....	79.0	56.5	31.2	140	2.81	8.2	58.3	26.6	31.4	0.5	Good
Minturki.....	78.5	69.8	29.7	89	3.92	11.2	60.2	25.7	40.8	0.9	Fair
Kawale.....	77.5	61.5	30.4	94	2.41	7.1	59.5	28.0	19.6	0.7	Weak
Kharkof.....	74.8	70.4	21.5	55	3.05	8.0	58.6	25.9	33.8	4.1	Fair
Progeny No. 2 (Ill.)...	74.1	52.5	27.9	63	4.00	15.4	60.4	23.6	38.8	1.6	Fair
Wis. Ped. No. 2*	73.7	60.1	27.9	60	2.60	12.3	59.3	27.7	31.3	0.3	Fair
Mich. Amber.....	69.1	40.9	27.6	53	2.06	11.4	57.5	27.2	38.8	5.6	Good
Fulhio.....	66.2	27.6	29.3	38	2.87	15.4	58.9	30.5	42.2	0.5	Good
Fulcaster.....	66.0	31.7	27.6	40	2.16	12.5	60.1	32.7	45.6	0.8	Fair
Purdue No. 1.....	65.8	34.6	27.9	39	2.41	15.4	56.7	26.2	34.8	9.7	Good
Trumbull.....	65.5	28.8	27.9	38	2.71	14.8	58.7	30.5	40.2	0.2	Good
Harvest Queen.....	65.2	41.2	24.8	47	1.95	12.3	59.4	29.8	53.4	0.5	Fair
Junior No. 6.....	63.7	27.1	29.0	23	1.92	14.0	56.2	30.0	40.0	0.4	Stiff
Rudy.....	63.2	26.6	27.9	38	2.34	12.2	58.9	34.3	41.8	1.1	Fair
Medit. Sel.....	63.0	29.9	23.0	34	2.46	14.9	59.0	24.3	32.8	1.5	Very weak
Poole.....	62.8	29.5	27.5	42	2.33	11.9	58.0	28.3	41.8	8.0	Good
Nabob.....	62.1	22.2	28.3	35	2.31	13.2	58.3	30.9	46.6	1.0	Good
Bald Rock.....	61.0	31.4	27.7	44	2.12	11.2	58.5	31.5	52.6	3.0	Good
Currell.....	60.6	29.0	26.2	39	2.32	14.2	59.3	27.4	39.8	0.6	Weak
Forward.....	60.3	30.5	29.9	43	2.34	13.3	59.1	31.6	47.8	0.3	Good
Gladden.....	57.0	23.2	29.0	39	2.58	16.2	57.6	27.4	47.2	7.1	Good
Nittany.....	56.7	26.0	27.9	42	2.33	16.1	56.6	32.6	39.4	1.7	Weak
Valprize.....	55.7	26.9	25.4	36	2.46	18.0	56.3	28.9	39.2	0.9	Stiff
Red Rock.....	54.2	23.8	26.1	53	2.08	11.7	57.9	32.8	49.6	10.2	Good
Honor.....	52.4	24.7	28.5	22	2.83	13.9	56.9	28.7	44.6	4.3	Stiff
Amer. Banner.....	51.8	23.2	25.8	23	2.72	14.5	56.8	29.6	49.2	5.0	Stiff
Purple Straw.....	41.7	26.0	18.3	41	2.76	13.9	59.5	25.4	48.2	2.4	Good
Leaps.....	35.6	8.8	18.1	36	2.56	16.8	59.5	28.9	51.8	0.1	Good
Red Hart.....	5.2	2.0	2.5								

\*4-year average.

†Average number of loose smut heads per rod row.



The characteristics desired in soft winter wheats in Indiana are high yielding ability, the winterhardiness of Minhardi or Purkof, gluten strength below 50 minutes, particle size index over 12.5, carotene content below 2.6 parts per million, test weight of 60 pounds per bushel, medium to large sized kernel, leaf rust and loose smut susceptibility as near nil as possible, and plants of medium height with the stiffness of straw found in Junior No. 6 or American Banner.

Since most of the desirable characters are dispersed among many varieties, the above character analysis becomes a valuable aid in selecting proper parental stock. It provides the breeder with the evidence he needs in supplying exact data concerning those major varietal characteristics in which he is vitally interested. So vital are these data in insuring ultimate success in breeding for a specific purpose, that a varietal series carried out in a manner somewhat similar to the above description seems so imperative that it might be regarded as an integral part of a wheat breeding program.

### SUMMARY

Analyses were made of 11 characters of 30 varieties of soft and semi-hard winter wheat grown at Lafayette, Indiana, during the five years 1933 to 1937, inclusive.

Wheat characters varied considerably in different varieties. Winter survival in the different varieties varied from 5.2 to 80.4% in the field and 2.0 to 76.6% under artificial freezing tests; yield from 2.5 to 31.2 bushels; gluten strength 22 to 140 minutes; color or carotene 1.92 to 4.00 p.p.m.; and particle size index 7.1 to 18.0%.

Soft wheat varieties were less winterhardy than semi-hard wheats under Indiana conditions. They possess a weaker gluten, a lower proportion of carotenoid pigments, and also produce a finer flour.

Fundamental data for several characters are presented which may serve as a basis for breeding suitable soft winter wheats.

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## EFFECT OF VARIETY AND STAND OF SOYBEANS ON RELATIVE YIELD AND PERCENTAGE OF TOTAL NITROGEN IN TOPS AND ROOTS<sup>1</sup>

W. B. ANDREWS and MARVIN GIEGER<sup>2</sup>

THE purpose of the experiment reported in this paper was to determine the percentage of the total weight and total nitrogen of the soybean plant contained in the roots of several varieties and the percentage of nitrogen in the tops and roots. From these data conclusions may be drawn as to the relative effect of varieties of soybeans on soil fertility.

Borst and Thatcher (2)<sup>3</sup> found the top-root ratio of Manchu and Peking soybeans at maturity when grown in cans at Columbus, Ohio, to be 13 to 1 and 10 to 1, respectively. Wiancko and Mulvey (4) found 10.9 pounds of nitrogen in the roots of soybeans where 81.8 pounds were found in the tops. Piper and Morse (3) report 165 pounds of nitrogen in the tops of soybeans and 9 pounds in the roots.

Andrews (1) found the yields of the roots of Laredo, Mammoth Yellow, and Ootootan soybeans grown in pots to be  $13.2 \pm 1.01\%$ ,  $20.2 \pm 0.69\%$ , and  $19.0 \pm 0.68\%$  of the total yield, respectively. The nitrogen contained in the roots was  $16.9 \pm 1.33\%$ ,  $20.1 \pm 0.62\%$ , and  $21.9 \pm 1.18\%$  of the total.

Soybeans were also grown in the field and the roots were harvested under an area with a radius of 2.5 feet from the plant (1). The yields of the roots of Laredo, Mammoth Yellow, and Ootootan were  $6.5 \pm 1.21\%$ ,  $10.7 \pm 1.35\%$ , and  $7.6 \pm 0.82$  of the total yield, respectively. The nitrogen contained in the roots was  $4.3 \pm 0.74\%$ ,  $6.4 \pm 1.18\%$ , and  $6.5 \pm 0.60\%$  of the total nitrogen.

The data obtained on the yield of roots depend upon the method of obtaining them. When cans or jars are used, the roots are not in a normal environment. When roots are harvested from plants grown in the field, it is too often the case that many of the smaller roots are lost, and, as a consequence, the results are inaccurate and the chemical analyses are not representative. After roots have been obtained, it is very difficult to remove all of the soil from them by washing and, therefore, this presents another factor which causes variation in the results. The data of Andrews reviewed above were so affected.

### THE PRESENT EXPERIMENT

The data reported in this paper were obtained from the roots of soybeans which were planted 8 to 10 feet apart in May 1933 on Ochlocknee sandy loam. The soybeans were harvested during the first two weeks of September. The earlier varieties were harvested first. The tops were removed at the surface of the ground, then a trench was dug around each stubble at a distance of 3.5 feet. The depth of the trench was 2 to 2.5 feet. The trench was then filled with water and the roots

<sup>1</sup>Contribution from the Departments of Agronomy and Chemistry, Mississippi Agricultural Experiment Station, State College, Miss. Received for publication February 21, 1938.

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<sup>3</sup>Figures in parenthesis refer to "Literature Cited", p. 437.

were washed out by pouring the water onto them. The roots which went deeper than the plowed soil were dug out with a tile spade. The soil settled to the bottom of the trench. The roots were then washed in clean water and the largest pieces of organic matter to which they were clinging were removed. They were then dried, weighed, ground, and analyzed for nitrogen and ash.

The roots thus obtained were from an area of 38.5 square feet. Incidentally, it was observed that only an insignificant quantity of roots was below the plowed soil. The few roots which were lower possessed practically no fibrous branches.

A field of thickly planted Mammoth Yellow soybeans was selected to determine the effect of stand on the ratio of root to total plant weight. The fine and coarse roots were separated by stripping the fine roots off of the coarser roots.

## RESULTS AND DISCUSSION

### PERCENTAGE OF TOTAL WEIGHT AND TOTAL NITROGEN IN ROOTS OF SEVEN VARIETIES OF SOYBEANS

The ash analyses of the roots were so variable due to the soil which could not be removed from them that the actual yields of the roots were converted into yields containing a uniform ash content of 8%, which is the approximate ash content of soybean tops, and the data are so reported in Table 1. The ash content of the Laredo actually varied from 8.6 to 36.4%.

TABLE 1.—*Percentage of total weight and total nitrogen in soybean roots.*

Variety	Percentage of total weight in roots	Percentage of total nitrogen in roots	No. of plants
Laredo.....	9.3 $\pm$ 0.61	8.6 $\pm$ 0.79	6
Otootan.....	16.0 $\pm$ 1.14	15.4 $\pm$ 1.21	6
Biloxi.....	16.1 $\pm$ 1.48	15.7 $\pm$ 1.13	4
Mamredo.....	9.4 $\pm$ 0.45	7.2 $\pm$ 0.46	6
Tanloxi.....	17.0 $\pm$ 0.71	16.4 $\pm$ 0.63	6
Delsta.....	15.8 $\pm$ 1.13	14.3 $\pm$ 1.01	6
Mammoth Yellow.....	14.9 $\pm$ 1.33	12.8 $\pm$ 1.66	6

The data in Table 1 show that the soybeans used in this test may be divided into two groups insofar as percentage of total weight and percentage of total nitrogen in the roots are concerned, namely, group 1, containing Laredo and Mamredo, which has about 9% of the total weight and about 8% of the total nitrogen in the roots; and group 2, containing Otootan, Biloxi, Tanloxi, Delsta, and Mammoth Yellow, which has about 16% of the total weight and about 15% of the total nitrogen in the roots.

The difference in the percentage of the total weight in the roots of the Laredo and that of the Mammoth Yellow is  $5.6 \pm 1.46$ . The difference in the percentage of the total nitrogen in the roots of the Laredo and that of Mammoth Yellow is  $4.2 \pm 1.84$ . These differences are highly significant. The differences between the percentage of the total weight and percentage of total nitrogen in the roots of the Laredo and Biloxi, Laredo and Otootan, Laredo and Tanloxi, and Laredo and Delsta are greater than the differences between Laredo and

Mammoth Yellow. The differences between these characteristics of Mamredo and any member of group 2 are greater than the differences between Laredo and Mammoth Yellow.

Mammoth Yellow, Mamredo, and Laredo mature at about the same time; the others are later maturing varieties. The Mamredo is assumed to be a natural cross between Laredo and Mammoth Yellow and it has a root system similar to that of the Laredo. The Delsta is a selection out of Mammoth Yellow and has a root system similar to that of the Mammoth Yellow. The Tanloxi is assumed to be a natural cross between Biloxi and Ootootan and has a root system similar to that of the two varieties.

#### EFFECT OF STAND UPON PERCENTAGE OF TOTAL PLANT FOUND IN ROOTS

When Mammoth Yellow soybeans were grown 8 to 10 feet apart, 14.9% of the total weight was in the roots while 30.0% of the plants, when grown in a thick stand, was in the roots. Only one sample was obtained from the thick stand which was grown on a different soil type; however, there were several plants in the sample. The probability that the difference is due to sampling is very small.

#### PERCENTAGE OF NITROGEN IN TOPS AND ROOTS OF SEVEN VARIETIES OF SOYBEANS

The data in Table 2 show that the percentage of nitrogen in the tops of the seven varieties of soybeans varied from 2.23 to 2.68, while that of the roots varied from 1.91 to 2.26. The percentage of nitrogen in the roots of these soybeans is relatively much higher than most analyses of other varieties which have been reported. This is probably due to the fact that the method used was such that practically all of the fine roots were recovered and to the fact that the data were converted to an 8% ash basis.

TABLE 2.—*The percentage of nitrogen in the tops and roots of seven varieties of soybeans*

Variety	Percentage nitrogen	
	Tops	Roots (8% ash basis)
Laredo.....	2.56 ± 0.074	2.06 ± 0.025
Ootootan.....	2.61 ± 0.042	2.26 ± 0.091
Biloxi.....	2.23 ± 0.150	2.13 ± 0.078
Mamredo.....	2.70 ± 0.041	1.91 ± 0.049
Tanloxi.....	2.55 ± 0.062	2.20 ± 0.022
Delsta.....	2.65 ± 0.022	2.15 ± 0.052
Mammoth Yellow.....	2.68 ± 0.014	1.92 ± 0.107

#### RELATIVE AMOUNT OF FINE AND COARSE ROOTS

The soybean roots obtained from the thick stand were separated into fine and coarse roots by stripping the fine roots off of the coarse roots. The fine roots were 59% of the total roots.

## PERCENTAGE OF NITROGEN IN FINE AND COARSE ROOTS

The percentage of nitrogen in the fine roots was 2.59, while that in the coarse roots was 0.87. The percentage of nitrogen in the fine roots of soybeans is sufficiently high for them to decompose without the micro-organisms drawing upon the soil nitrogen; however, the coarser roots should have little immediate effect.

## SUMMARY AND CONCLUSIONS

Six varieties of soybeans were grown in the field, each plant spaced 8 to 10 feet apart. The roots were washed out of the soil under a 38.5 square foot area. Practically all of the roots were recovered. In addition one sample of Mammoth Yellow soybean tops and roots was obtained from a thickly planted field. There were sufficient samples in the varietal comparison to apply statistics, but there was only one sample of thickly spaced soybeans. On the basis of the thickly spaced soybeans, the data on the thinly spaced soybeans could probably be doubled. The data show that:

1. The varieties of soybeans studied fall into two groups with respect to their root systems, namely, group 1, containing Laredo and Mamredo, which has about 9% of the total weight and about 8% of the total nitrogen in the roots; and group 2, containing Ootootan, Biloxi, Delsta, Mammoth Yellow, and Tanloxi, which has about 16% of the total weight and about 15% of the total nitrogen in the roots.
2. The quantity of roots and the quantity of nitrogen left in a soil by the roots of a good crop of soybeans is too small to affect the following crop materially.
3. The roots of the soybeans grown in a thick stand composed 30% of the total weight of the plant; those of the thin stand composed 15% of the total weight of the plant.
4. Fifty-nine per cent of the roots were fine and 41% were coarse.

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## AVAILABLE POTASSIUM IN ORCHARD SOILS AS AFFECTED BY A HEAVY STRAW MULCH<sup>1</sup>

I. W. WANDER and J. H. GOURLEY<sup>2</sup>

IN a recent brief article (8),<sup>3</sup> the authors pointed out the large amounts of available potassium found beneath old straw mulches as compared with adjacent cultivated land. Since then, additional confirmatory evidence has been obtained in a mulched pear orchard on a Mahoning silty clay loam at Strongsville, Ohio. It is our purpose here to present the data on which these observations were based, together with those obtained on a similar orchard soil to which potassium fertilizers have been applied.

Studies were begun in the orchards of the Ohio Agricultural Station in 1928 to determine the need for other elements than nitrogen, particularly phosphorus and potassium. About that time it was noticed that each year there was a definite scorching of the foliage which suggested potassium deficiency. Each year since, the trees in certain areas of the orchards have shown the same symptoms. One season (1936) a block of trees was left unsprayed to determine whether the trouble was due to injury from sprays or spraying. The leaves again showed "burned" edges, although apple scab was so severe in that year that diagnosis was made difficult. It should be added, however, that there is no evidence that the scorching of the foliage has particularly affected the growth or yield of the trees; neither has there been any significant increase in yield as a result of the fertilizer treatments.

### OBSERVATIONS IN ORCHARD J

The orchard in which the fertilizer treatments were begun in 1928 is known as orchard J and consists of the varieties Baldwin and Stayman Winesap. Planted in 1922, it was cultivated for seven years and then put down to blue-grass sod. There has been an occasional light disking along the tree rows. While this orchard is not particularly involved in the present discussion, the treatments are here given together with a record of the downward translocation of available potassium during 10 years of treatment in order to show that potassium is "fixed" in this soil. At first the rate of application was probably too low, but later the rate was increased (Table 1). At all times the rate of nitrogen applications was in accordance with that recommended to orchardists of the state.

From Fig. 1 it will be seen that available potassium is present in any considerable amount only at a very shallow depth in the treated plats of this particular orchard. The characteristic "fixing" of potassium (4) presents a difficult mechanical problem to orchardists who wish to supply it to fruit trees. This tendency for potash to be fixed by the surface soil, above the zone in which the absorbing roots of

<sup>1</sup>Contribution from the Department of Horticulture, Ohio Agricultural Experiment Station, Wooster, Ohio. Received for publication February 21, 1938.

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<sup>3</sup>Figures in parenthesis refer to "Literature Cited," p. 445.

TABLE 1.—Fertilizer treatment of individual trees in pounds in orchard J.

Plat No.	Treatment	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937
3.....	Nitrate soda	1 3/4	2	2 1/4	2 1/2	2 3/4	3	3 1/4	3 1/2	3 3/4	4
	Superphosphate	1 3/4	2	2 1/4	2 1/2	2 3/4	3	3 1/4	3 1/2	3 3/4	4
	Muriate potash	7/8	1	1 1/8	1 1/4	1 3/8	1 1/2	3/4	2 3/4	2 3/4	3
5.....	Nitrate soda	1 3/4	2	2 1/4	2 1/2	2 3/4	3	3 1/4	3 1/2	3 3/4	4
	Superphosphate	1 3/4	2	2 1/4	2 1/2	2 3/4	3	3 1/4	3 1/2	3 3/4	4
7.....	Nitrate soda	1 3/4	2	2 1/4	2 1/2	2 3/4	3	3 1/4	3 1/2	3 3/4	4
	Muriate of potash	7/8	1	1 1/8	1 1/4	1 3/8	1 1/2	3/4	2 3/4	2 3/4	3
9.....	Untreated	—	—	—	—	—	—	—	—	—	—

trees are abundant, has been assigned as a factor responsible for the negative results often reported from potash fertilization of apple orchards.

Determinations made by a quick test (7) showed that at the end of seven years the available potassium content of the surface 2 inches of soil was "very high" and in the next 2 inches "medium" as compared with a "low" content prior to treatment. In other words, there had not been any downward translocation of available potassium below 4 inches. At the end of 10 years there had been an additional downward movement, but it must be noted that the rate of application had been approximately doubled since 1933. Potassium is now "high" to "very high" to a depth of 6 inches, but still not deep enough to reach the majority of roots.

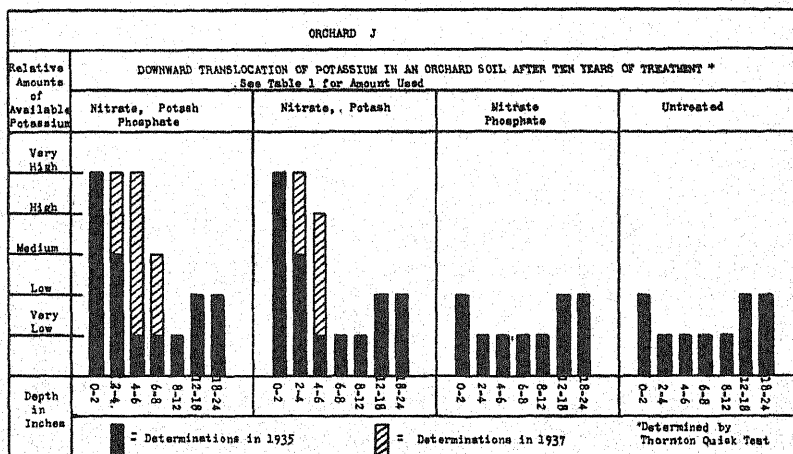


FIG. 1.

## AVAILABLE POTASSIUM IN MULCHED AND CULTIVATED ORCHARDS

In contrast with the above situation a similar but more complete study has been made of mulched and cultivated orchards which have at no time received applications of potash fertilizers. These orchards are growing on a soil of the same type as Orchard J (Wooster silt loam). In this soil the trees root to a depth of 5 to 6 feet, although the majority of fibrous roots are within the first 2 to 3 feet (3).

### OBSERVATIONS IN ORCHARDS A AND C

#### TREATMENTS

These orchards offer excellent facilities for study because of the long-time treatments of mulch and tillage. Orchard A was planted in 1893, cultivated for six years, then seeded to bluegrass and since then has been heavily mulched with straw or other litter for a total of 38 years. Wheat straw has been used most extensively. No definite record is available of the total amount of mulch added to these trees through the years, but it has been sufficient to prevent the growth of grass or weeds beneath the trees. A conservative estimate of this amount would be about 150 to 200 pounds of straw or its equivalent in other material per year per tree. Since straw contains about 1% of potassium, most of which is water-soluble, there would have been applied about  $1\frac{1}{2}$  to 2 pounds of potassium per tree. In the course of 30 years, since the trees had reached maturity, there has been applied a total of about 45 to 60 pounds of potassium per tree, equivalent to 2,400 to 3,200 pounds of potassium per acre of surface mulched. Incidentally, the mulch system of culture has been satisfactory as is shown by the high productivity of the orchard. The average annual yield of 15 of the better known varieties has been 15.5 bushels per tree for 26 years, or the equivalent of 620 bushels per acre at the distance the trees are planted (33 by 33 feet).

Orchard C was planted in 1915 and divided into two equal blocks. One block has been continuously cultivated with cover crops of soybeans for the summer and rye for the winter. Some years oats and sudan grass have been used. The other block was planted in sod and the mulch system was begun at once. The growth and yield of the trees under both systems of culture have been above average for this region, although recently the mulch has given somewhat superior results (3).

#### METHOD AND POSITION OF SAMPLING

Samples were taken by means of a soil tube at 8-inch levels to a depth of 48 inches. Whenever large roots or stones were encountered the soil tube was moved a few inches and the sampling started again. In securing the soil for samples both the mulch and sod were completely removed. Samples were first taken under the heavy mulch at the drip of the branches, then from under the sod in the inter-spaces between the trees at positions as comparable as possible, as far as soil character was concerned, to those from the mulched area. Samples were taken in a similar manner in the block of trees under cultivation. As a check or comparison



samples were also taken from an adjacent field in an unfertilized plat which had been in a 3-year rotation of potatoes, wheat, and clover since 1894.

#### METHOD OF DETERMINATION

Exploratory determinations were first made by means of a quick test (7). However, the final determinations here reported were based on the exchangeable potassium of the samples. This was done by the method outlined by Bray and Whillhite (2). In this method the exchangeable bases of the soil are replaced by the ammonium ion supplied by a neutral normal ammonium acetate solution. It is generally believed by soil chemists that the potassium displaced from a soil by treatment with a neutral normal ammonium acetate solution is as definitely related to the total available potassium in the soil as the quantity indicated by any laboratory method in use (1).

Ten grams of the air-dried soil sieved to pass 2 mm were placed in a 25-cc porcelain Gooch crucible over a neatly fitting disc of No. 1 Whatman filter paper previously moistened and pressed on the perforated bottom. The leaching solution was contained in a 250-cc volumetric flask with a stopper carrying two straight pieces of 3-4 mm glass tubing, one 6.5 and the other 7 cm long. When the filled flask was supported, inverted over the crucible containing the sample covered with a filter disc to prevent channelling of the soil and with a Pyrex beaker beneath to receive the percolate, the leaching continued without attention, as the double tube arrangement automatically admitted fresh solution to the crucible as required. The leaching process required about 8 hours.

The entire percolate was evaporated to dryness in the Pyrex beaker on a water bath and the residue of acetates ignited over an asbestos center wire gauze and Bunsen burner, slowly at first then at full heat until converted to carbonates and most of the free carbon burned off. After the addition of a slight excess of dilute HCl, the solution was again evaporated to dryness. The potassium was determined colorimetrically as described by Morris and Gerdel (5). The analytical procedure is simple, and close agreement between determinations was invariably obtained.

#### RESULTS

The quantitative results thus obtained indicate that available potassium was quite high from 24 to 32 inches beneath the heavy mulch in both orchards A and C (Table 2). The entire cultivated area, as well as the unfertilized field plat, was notably low in available potassium (Fig. 4). Intermediate to these extremes was the amount of available potassium present in the soil beneath the surface of the bluegrass sod near the heavily mulched trees. The soil beneath two of the trees in the mulch system (orchard C) has a content of approximately 1,000 pounds per acre of available potassium at a depth of 24 inches, while the soil beneath a tree 35 feet away in cultivation contained less than 175 pounds per acre at the same depth (Fig. 2).<sup>4</sup>

The same conditions exist in Orchard A but are somewhat less prominent (Fig. 3). Although limits for the amount of available potassium necessary for certain crops have not been satisfactorily determined as yet, Prince and Blair (5) state that for corn, wheat, oats,

<sup>4</sup>Each 8-inch horizon weighs in the neighborhood of 2 million pounds per acre of air-dry soil. Then each 0.01% K found represents 200 pounds per acre.

TABLE 2.—*Percentage of exchange potassium in orchard soil under different systems of culture.*

Tree No.	Heavy mulch, depth of sample, inches, taken 8 ft. from tree trunk					Sod, depth of sample, inches, taken 25 ft. from tree trunk						
	0-8	8-16	16-24	24-32	32-40	40-48	0-8	8-16	16-24	24-32	32-40	40-48
Orchard A												
128.....	0.025	0.024	0.027	0.027	0.020	0.017	0.018	0.014	0.013	0.012	0.012	0.011
278.....	0.024	0.028	0.029	0.021	0.010	0.009	0.023	0.013	0.011	0.008	0.004	0.008
136.....	0.026	0.025	0.019	0.010	0.008	0.010	0.031	0.029	0.013	0.009	0.008	0.012
Orchard C*												
55.....	0.049	0.049	0.047	0.011	0.011	0.009	0.014	0.016	0.010	0.008	0.006	0.004
4/3.....	0.050	0.052	0.050	0.023	0.009	0.005	Cultivated (sampled 25 feet from tree trunk)					
5/2.....	0.017	.014	.011	.008	.004	.005	0.009	0.012	0.007	0.006	0.004	0.004
4/1.....	0.010	.006	.009	.009	.004	.005	—	—	—	—	—	—
3-year rotation plat 1.....	0.006	0.009	0.009	0.011	0.008	0.009	—	—	—	—	—	—

\*Mulch was 7 feet from trees in this orchard.

\*Mulch was 7 feet from trees in this orchard.

clover, and alfalfa on loam soils 80 pounds or less per acre of available potassium are insufficient. One hundred and forty pounds per acre or above appear to be sufficient, other conditions being favorable. Even though these annual crops are very different in their root-

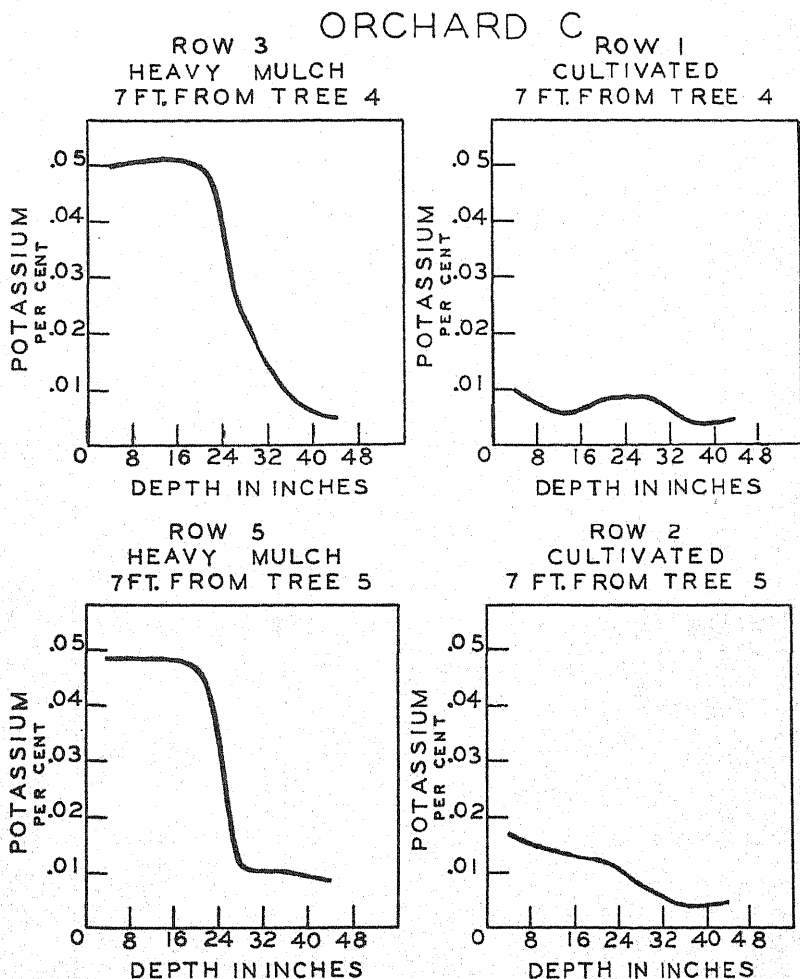


FIG. 2.

ing and growing habits than apple trees, nevertheless it would appear that the lower amounts of available potassium found in these orchards represent sufficient quantities to maintain satisfactory growth and yield.

The fact that a relatively large amount of available potassium is found at a depth of 2 to 3 feet under mulch is highly significant in the light of the characteristic fixation of potassium in the first few inches

of surface soil. Where potash fertilizers have been applied to the Wooster silt loam for a period of 10 years very little downward movement of available potassium has been observed, as indicated earlier in this paper. In no case was any potash applied to the trees under the mulch system.

## ORCHARD A

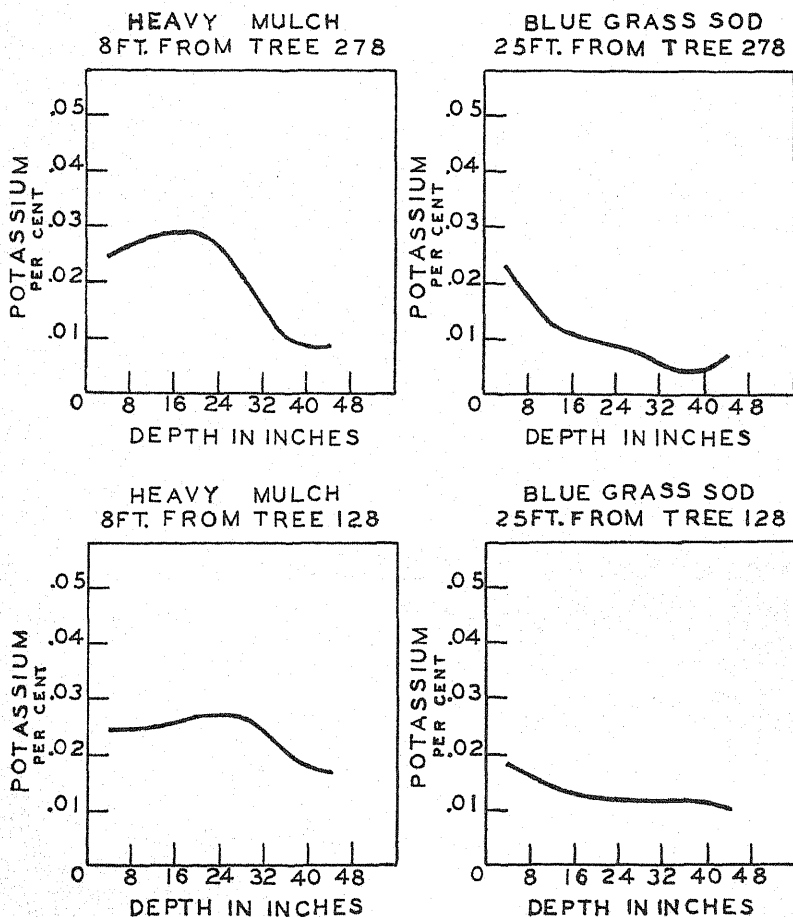


FIG. 3.

## SUMMARY

Data are here presented to show the amount of available potassium under three different systems of culture, *viz.*, mulch, sod, and cultivation with cover crops, which have been maintained over a relatively long period of time on a Wooster silt loam soil. The investigations included both fertilized and unfertilized plats.

Both a quick test and a method including the quantitative determination of replaceable potassium were used. On plats under grass and clean cultivation with cover crops and treated with a potash fertilizer, it was found through "quick" tests that there had not been any appreciable downward movement of available potassium beyond a depth of 6 inches. The treatments have covered a period of 10 years during which there has been an increasing rate of potash application. At the present time (1938) potash fertilizers are applied at the rate of nearly 300 pounds per acre per year on the area under the trees.

## CHECKS

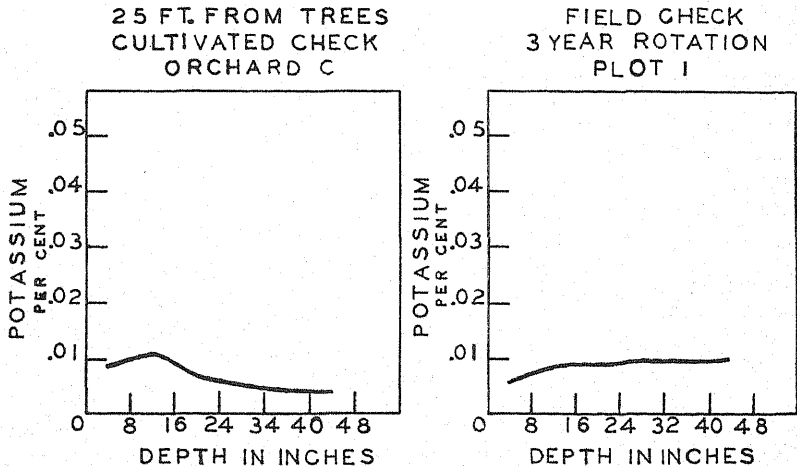


FIG. 4.

The data obtained by quantitatively determining the replaceable potassium of soil under a heavy mulch that has been maintained for a period of 22 to 38 years, upon which no potassium had been added other than that supplied by the mulch, showed that available potassium was very high to a depth of from 24 to 32 inches. This is in contrast to a lesser amount found under the adjacent bluegrass sod and a much smaller amount found under plats in cultivation with cover crops.

Available potassium was found to be "low" to "very low" in a nearby unfertilized field plat which was taken as a check on the cultivated plats.

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## NOTES

### A USEFUL SEED BLOWER FOR THE GRASS BREEDER

SINCE the glumes of many grasses fail to free the caryopses upon threshing, the distinction in such cases between empty florets and those containing caryopses often is difficult.

Chewing a few florets from each plant can hardly be considered a satisfactory method of estimating the plant's ability to produce seed. Crushing 100 or more florets from each plant with tweezers is too laborious and costly a method of determining the percentage of caryopses in several thousand plants.

A recent paper<sup>1</sup> describing the merits of a Leendertz blower for making purity determinations of commercial lots of Kentucky bluegrass seed suggested a means by which this problem may be met satisfactorily. Later correspondence with several official seed analysts<sup>2</sup> disclosed the fact that blowers of various types were being used in seed laboratories to assist with purity determinations. Borrowing from and adding to the ideas thus obtained, the author constructed the blower shown in Fig. 1.

Accumulating evidence indicates that climatic variations influence the percentage of florets which develop caryopses. Therefore, if a comparison of the ability of individual plants to produce seed is desired, all samples of seed to be tested should have been produced during the same set of weather conditions.

To reduce the effect of the climatic factor all grass seed harvested for caryopses determinations at Tifton, Georgia, was taken from heads possessing ripe florets and green peduncles. An effort was made to harvest all samples from any one species in the shortest time possible. By labeling tags and seed packets in advance and by keeping them in order, four men were able to collect from 1,000 to 1,500 samples per day. To facilitate separation and to make all results comparable, the seed samples for caryopses determination were oven dried at 80° C for a period of 4 or 5 days prior to making the determinations.

In the cleaning procedure from 0.5 to 1.0 gram of threshed seed from each plant is weighed and placed in the seed tubes. The empty florets are then removed by subjecting each sample to a uniform blast of air in the blower and the percentage of caryopses is determined by

<sup>1</sup>BROWN, E. O., and PORTER, R. H. An improved method of testing seeds of Kentucky bluegrass (*Poa pratensis* L.). Proc. Assoc. Off. Seed Anal. No. Amer., 27:44-49. 1935.

<sup>2</sup>E. Brown, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C.; M. T. Munn, N. Y. State Agr. Exp. Station, Geneva, N. Y.; E. M. Stoddard, Conn. Agr. Exp. Station, New Haven, Conn.

weighing the sample after the empty florets have been removed. Using a chainomatic balance it is possible for one man to make 10 to 15 determinations per hour.

Last winter the percentage of caryopses in more than 5,000 samples of seed was determined with the aid of the blower described here.

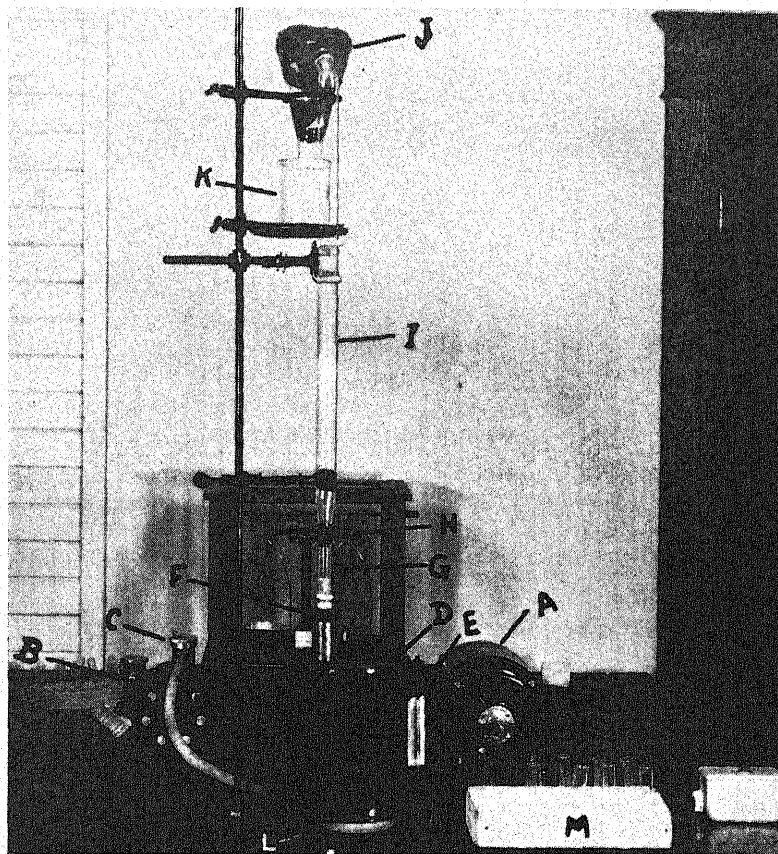


FIG. 1.—A seed blower for grass seed. The electric motor (A) pulls the blower (B) possessing adjustment (C) for regulating the air pressure. The air from the blower passes into (D), a wide-mouthed syrup pail, which acts as a pressure chamber. A mercury manometer (E) permits pressure regulation for different kinds of seeds and insures uniform blowing. Seed container (G) is a glass tube 1.5 mm. in diameter and 8 cm. long, in this case an empty photographic developer tube. One end of this tube is covered with a good grade of cotton sheeting or bolting silk held in place with a rubber band. A short piece of rubber hose (H) makes a positive connection between the seed container and the blowing tube (I), which is 24 inches long. A hole burned in one side of tube (I) and permits the empty florets to enter beaker (K). A circle of large rubber tubing (L) under can (D) and the rubber cork (F) act as springs to keep seed container (G) in place and to prevent air losses. A block of wood (M) having holes numbered from 1 to 10 makes possible the running of 10 samples at one time without numbering each tube.

Seedlings from one of the *Digitaria* species produced seed ranging from 0 to 38% of florets containing caryopses. Variations in the percentage of florets containing caryopses in *Paspalum notatum* seedlings ranged from 10 to 98%. Such data supply a scientific basis for the elimination of plants which do not produce good seed.

A few *Digitaria* florets containing anthers (anthers are not exerted in all florets) could not be readily separated from florets containing caryopses. After the empty florets had been removed from the sample with the blower, the few florets containing anthers were removed by crushing them with a sharp scalpel.

It is doubtful if the blower will prove equally suitable for all types of grass seed. The principle of the machine, however, is good and the results obtained at Tifton would seem to warrant its use by grass breeders interested in measuring the seed setting capacity of the grasses with which they are working. Even where complete separation with the blower is not possible, it will remove a large proportion of light material and greatly reduce the hand picking necessary for a complete separation.—GLENN W. BURTON, *Division of Forage Crops and Diseases, U. S. Dept. of Agriculture, Tifton, Georgia.*

#### RESISTANCE OF CERTAIN WHEAT VARIETIES TO ATTACK BY THE WHEAT STEM MAGGOT, *MEROMYZA AMERICANA* FITCH

A STRIKING difference in the amount of damage done to varieties of spring wheat was noted by the author on the DeKalb experiment field of the Illinois Agricultural Experiment Station on July 7, 1937. The result of the observation is here offered (Table I) for the information of investigators who may be interested.

TABLE I.—Percentage of tillers of wheat showing damage by the wheat stem maggot on the DeKalb experiment field of the Illinois Agricultural Experiment Station, July 7, 1937.

Variety	Infestation, %
Thatcher.....	0.5
Progress.....	0.5
Klein-C (17)0*	9.0
Klein-C 390½*	11.0
Sturgeon.....	0.1
Illinois No. 1 (Mann).....	0.1
Comet.....	0.05
Komar.....	0.05
Illinois 1A.....	1.0
Purdue 38.....	1.0

\*Argentine varieties.

The wheat was planted May 11, 1937 (late), and the heads of undamaged tillers were still green at the time of observation. Dead heads were used as a criterion of infestation following dissection of sufficient numbers to assure us that the insect was responsible for the death in practically all cases. The differences were so easily apparent that they could not escape the most casual inspection.—J. H. BIGGER, *Illinois Natural History Survey, Urbana, Ill.*



## BOOK REVIEWS

### PRODUCTION OF SEED OF HERBAGE AND FORAGE LEGUMES

*Edited by R. O. White. Aberystwyth, Wales: Imp. Bur. Plant Genetics. 48 pages, illus. 1937. 51.*

TEN counties report on producing seed of forage and herbage legumes. The methods of planting legumes for seed purposes are discussed under the headings of soil types, seedbed preparation, fertilization, and seeding rates. Methods of gathering seed, periods of harvest, handling, conditioning, threshing, cleaning, and disposal of the seed is explained. This publication is of value to the plant breeder and seed-producing organizations. (R. E. B.)

### COLLECTION OF NATIVE GRASS SEED IN THE GREAT PLAINS, U. S. A.

*By F. J. Crider and M. M. Hoover. Aberystwyth, Wales: Imp. Bur. Plant Genetics. 15 pages, illus. 1937. 21.*

SEVERAL rapid mechanical methods for harvesting large quantities of seed of the important species of the Great Plains area are described and photographically illustrated. Because native grasses are recognized as the basis of a general revegetation program of the Great Plains States, this publication will be beneficial to those interested in gathering seed. The types of equipment described and illustrated are flexible and would be adapted for seed collection of many pasture plants. (R. E. B.)

### TECHNIC OF GRASS SEED PRODUCTION AT THE WELSH PLANT BREEDING STATION

*By Gwilym Evans. Aberystwyth, Wales: Imp. Bur. Plant Genetics. 36 pages, illus. 1937. 51.*

THE technics of propagating large quantities of seed of newly developed strains of 14 grass species are explained. Seed multiplication of new grass strains is achieved in three stages, the first from a limited number of plants selected by the grass breeder, the second on a limited field scale, and the third in terms of several fields for each strain. The first stage of multiplication is carried out at the station in glass houses. The second and third stages are carried on by growers who are paid a certain fixed sum for a 3-year period. All the multiplication operations are supervised by the station. Detailed information for establishing plantings for seed multiplication purposes and preparing the seed for disposal to farmers is given.

A great amount of pioneer work has been done by the Welsh Plant Breeding Station and this publication will be applicable to grass work in this country. (R. E. B.)

### THE 1937 PROCEEDINGS OF THE SOIL SCIENCE SOCIETY OF AMERICA

*Ann Arbor, Mich.: Edwards Bros. Lithoprinted from typewritten pages: cloth bound, IX+602 pages, illus. 1938. \$5.*

THIS volume contains the 91 papers presented at the annual meeting of the Soil Science Society of America held in Chicago November 30 to December 4, 1937. Most of the papers are given in full with a few in abstract form.

The five papers on "The Significance of Structure in Soils", presented on the general program, open the volume, with the papers presented on the several sectional programs grouped together as follows: Section I, Soil Physics, including joint sessions with Sections II and V, 15 papers; Section II, Soil Chemistry, including joint sessions with Sections I, IV, and V, 14 papers; Section III, Soil Microbiology, including a joint session with the Crops Section of the American Society of Agronomy, 18 papers; Section IV, Soil Fertility, 11 papers; Section V, Soil Genesis, Morphology, and Cartography, 19 papers; and Section VI, Soil Technology, 9 papers.

Minutes of the business meeting of the Soil Science Society and of the American Section of the International Society of Soil Science, together with other reports and announcements, make up the remainder of the volume. A table of contents and an author index are helpful supplements, while "Suggestions for the Effective Presentation of Papers" might well be perused to advantage by all who present papers on scientific programs.

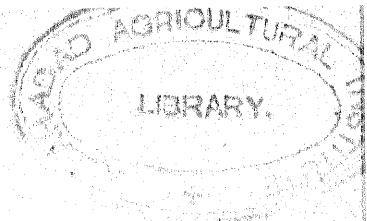
Volume II maintains the same excellent mechanical standards set by Volume I and with its very substantial cloth binding presents a most creditable appearance. (J. D. L.)

## AGRONOMIC AFFAIRS

### NEWS ITEMS

THE NORTHEASTERN SECTION of the Society will meet jointly with Section O of the American Association for the Advancement of Science at Ottawa, Canada, June 27 to July 2. For further details on this meeting, write to Orman E. Street, Secretary-Treasurer of the Northeastern Section, Connecticut Agricultural Experiment Station, Tobacco Sub-Station, Windsor, Conn.

THE EIGHTH annual Spragg Memorial Lecture, sponsored by the Department of Farm Crops, Michigan State College, East Lansing, Mich., to commemorate the work of the late Frank A. Spragg, pioneer Michigan plant breeder, was delivered at the College on April 21 by the Honorable Henry A. Wallace, Secretary of Agriculture. The title of Mr. Wallace's address was "Corn Breeding Experience and its Probable Eventual Effect on the Technique of Livestock Breeding." The lecture is available in printed form from the Department of Farm Crops, Michigan State College.



# JOURNAL OF THE American Society of Agronomy

VOL. 30

JUNE, 1938

No. 6

## THE NUMBER OF LEGUME BACTERIA IN COMMERCIAL CULTURES AS RELATED TO NODULE FORMATION<sup>1</sup>

ALVIN W. HOFER<sup>2</sup>

LABORATORY studies of legume inoculants incapable of nodule formation by greenhouse tests have been carried on for several years at the New York State Agricultural Experiment Station at Geneva. Early results indicated that the inability to produce nodules might have been due to insufficient numbers of bacteria in the cultures. A study was made, therefore, for three purposes, *viz.*, (a) to determine approximately how many bacteria are required for inoculation of individual seeds, (b) to develop laboratory standards upon the basis of this information for judging whether cultures are actually deficient in numbers of nodule bacteria, and (c) to apply these standards, if possible, to the improvement of some of the brands which frequently failed to produce nodules.

Early studies of the numbers of legume bacteria necessary per seed (3,9)<sup>3</sup> were not successful, probably because of the inclusion in the tests of impure humus and soil cultures. In those types of inoculants which are made by mixing unsterilized material with a suspension of legume bacteria, other micro-organisms from the soil or humus may develop in great numbers upon the nutritive material provided for the legume bacteria. Recent investigation (7) has shown that peat cultures may carry great numbers of slightly fluorescent organisms, the colonies of which are almost impossible to distinguish on the culture plate from colonies of legume bacteria.

Perkins (10) stated, in regard to the first point (a), that inoculation is rather a matter of chance, since it depends upon contact between an organism and a rootlet. Nevertheless, he believed that a rather definite minimum number of nodule bacteria is required to produce maximum infection. In his investigations he found that apparently each soybean seed required 10 to 100 legume bacteria while maximum results were obtained with 25 to 50.

<sup>1</sup>Contribution from the Division of Bacteriology, New York State Agricultural Experiment Station, Geneva, N. Y. Approved by the Director for publication as Journal Paper No. 245, January 4, 1938. Received for publication January 5, 1938.

<sup>2</sup>Associate in Research.

<sup>3</sup>Figures in parenthesis refer to "Literature Cited", p. 459.

## METHODS

In the present investigation, similar work was conducted with alfalfa and clover. Since each culture should carry one or more nodule-forming bacteria per seed, it was necessary to know how many other organisms, by plate count, would be required to insure the presence of that one organism. While this number would probably not be the same for every culture, nevertheless, if it were determined approximately, there was a chance that definite laboratory standards could be set up. These would be based upon the number of bacteria required to inoculate individual seeds and upon the number of seeds in a pound. The number of bacteria necessary by plate count could then be expressed in thousands or millions per pound of seed. After that, plate counts of commercial cultures could be compared with these figures for testing and possible revision of the standards as suggested under the second point (b) above. When standards were worked out, at least approximately, it seemed that they should prove useful in determining whether the samples that failed to produce nodules in the routine tests were actually deficient in the number of bacteria present and in securing information to assist in improving commercial cultures, as suggested under (c) above.

The first point (a) was studied by making simultaneous agar plate counts and plant counts upon commercial cultures of inoculants 2 to 8 months old. The ratio of plate count to plant count was used as the measure of how many cells among those present by plate count would be capable of forming nodules. The plate count indicated the number of bacteria present as determined by laboratory methods, while the plant count showed the number of nodule-forming organisms in each population.

In the laboratory, the counts were made by inoculation of triplicate plates from each dilution. In the case of the agar cultures, the dilutions ranged from 1:1,000 to 1:100,000,000; in the sand cultures, the dilutions covered the range from 1:100 to 1:1,000,000 per gram of sand. All counts were made upon medium 79 of Fred and Waksman (4) with 3 grams of Bacto yeast extract per liter instead of yeast water as the nitrogen source. Plates were allowed to remain in a 25° C incubator until colonies were well developed; usually about 5 days for alfalfa, clover, pea, or bean bacteria and 10 or 12 days for soybean and cowpea cultures.

The plant counts in the greenhouse were made by inoculating from each of the six upper dilutions used for plates, five (6-oz. Signet) bottles of Crone's agar (1) on the surface of which six or eight alfalfa or clover seeds had been planted. All seeds were treated in 2% chlorine solution for one-half hour, rinsed six times and dried before use. Each bottle of seeds received a 1-cc portion of inoculum, which was similar to the procedure used in making plate counts. Then, after the bottles had stood in the laboratory for 24 hours, they were kept in the greenhouse until the plants had grown and nodulation was well developed throughout the lower dilutions, a period usually of about 6 weeks.

At this time, each bottle found to have in it a nodule-forming organism, as shown by the formation of one or more nodules, was marked as plus, while each bottle without nodules was marked as minus. Since only five bottles were used per dilution, the estimates of numbers by the plant count were made by multiplying the number of positives by two and finding the most probable number of actual nodule-forming bacteria originally added by reference to mathematical tables (probability Table A, Halvorson and Ziegler, 6). Occasionally, the culture under test was much better than had been anticipated, and in such cases nodulation occurred in all of the bottles. In other cases where the culture was poor, nodulation did not occur in any of the bottles. In the majority of cases, however,

nodulation occurred in the lower dilutions and became more scattered in the higher, thus making possible a rough estimate of the number of bacteria present by use of a probability table.

Routine legume inoculant tests during the course of these investigations, and reported in Table 2, were made in sand taken from the subsoil of a field near Oaks Corners, N. Y. This was sterilized in a moist condition for 2 hours at 15 pounds steam pressure and watered with sterile distilled water and sterile Crone's solution (1).

## RESULTS

### BACTERIA REQUIRED PER SEED

Table 1 shows the plate counts and plant counts from a number of cultures. The ratio  $\frac{\text{bacteria present by plate count}}{\text{bacteria that form nodules by plant count}}$  is quite variable for individual cultures. Since this figure represents also the minimum number of cells required by plate count if there is to be an average of one infective organism per seed, it is apparent that for different cultures this figure is not constant. Thus, although the average ratio in Table 1 would seem to be about 25 organisms by plate count for each 1 by plant count, for the purpose of setting up standards it seemed better to assume that 5 to 40 legume bacteria were necessary per seed. These figures were chosen also upon the basis of preliminary inoculant tests made for the purpose of checking the accuracy of the standards.

TABLE 1.—*Comparison of plate and plant counts on legume inoculants.*

Sample No.	Count, total numbers of bacteria in culture		Plate count ratio
	Plate method	Plant method	Plant count ratio
Alfalfa			
1	26	0.48	54.0
2	200	7.50	27.0
3	806	29.00	28.0
4	3,000	112.00	27.0
5	17	1.60	10.5
6	900	18.00	50.0
Clover			
7	180	72.00	2.5
8	43	1.65	26.0
9	32	0.90	39.0
10	67	2.78	22.0
11	2,400	141.00	17.0
12	6,500	3,490.00	2.0
13	7,000	542.00	13.0
14	396	17.00	23.0

### DEVELOPMENT OF LABORATORY STANDARDS

Assuming that 200,000 alfalfa seeds are present in a pound (for exact figures, see Fred, *et al.*, 5), to have 5 bacteria per seed, cultures should contain at least 1,000,000 bacteria per pound of seed they are

to inoculate; 8,000,000 per pound would probably be more certain to result in nodulation. Although these figures were derived upon the basis of alfalfa seed, they have proved helpful even with such large-seeded plants as peas. Greenhouse tests of more than 300 legume inoculants on which plate counts have been made show that, as with culture A (1932) in Table 2, the cultures with fewer than 1,000,000 bacteria per pound of seed usually fail to produce nodules. Those with more than 8,000,000 bacteria (apparently *Rhizobium*) per pound practically always induce nodulation, unless the proportion of infective

TABLE 2.—Plate counts and nodule formation by samples of three brands of legume inoculants.

Year	Plant group	Nodule formation*	Bacteria per pound of seed	Year	Plant group	Nodule formation*	Bacteria per pound of seed
Culture A							
1932	Alfalfa	S	17,000,000	1937	Alfalfa	S	270,000,000
1932	Alfalfa	U	280,000	1937	Alfalfa	S	173,000,000
1932	Alfalfa	U	900,000	1937	Alfalfa	S	193,000,000
1932	Alfalfa	S	16,000,000	1937	Alfalfa	S	6,000,000
1932	Clover	S	13,000,000	1937	Alfalfa	S	193,000,000
1932	Clover	U	None found	1937	Alfalfa	S	670,000,000
1932	Clover	U	2,000,000	1937	Clover	S	20,000,000
1932	Clover	U	2,000,000	1937	Clover	S	7,000,000
1932	Clover	S	7,000,000	1937	Peas	S	31,000,000
1932	Clover	S	32,000,000	1937	Peas	S	30,000,000
1932	Clover	U	550,000	1937	Beans	S	34,000,000
				1937	Peas, beans, lima beans, lupines	S	107,000,000
				1937	Peas	S	
					Beans	S	
					Lima beans	U	
					Lupines	S	350,000,000
Culture B							
1935	Alfalfa	U	94,000,000	1937	Alfalfa	S	260,000,000
1935	Alfalfa	U	86,000,000	1937	Alfalfa	S	6,000,000
1935	Alfalfa	U	91,000,000	1937	Alfalfa	S	103,000,000
1935	Alfalfa	U	23,000,000	1937	Alfalfa	S	58,000,000
1935	Alfalfa	U	41,000,000	1937	Alfalfa	S	53,000,000
1936	Alfalfa	P	28,000,000	1937	Alfalfa	S	257,000,000
1936	Alfalfa	P	96,000,000	1937	Alfalfa	S	401,000,000
1936	Alfalfa	P	93,000,000	1937	Alfalfa	S	46,000,000
1936	Alfalfa	P	18,000,000	1937	Alfalfa	S	43,000,000
1936	Alfalfa	P	30,000,000				
1936	Alfalfa	P	20,000,000				
Culture C							
1935	Peas	U	8,000	1937	Peas	S	157,000,000
1935	Peas	U	37,000	1937	Peas	S	34,000,000
1935	Peas	U	830,000	1937	Peas	S	57,000,000
1935	Peas	U	12,000	1937	Peas	S	67,000,000
1935	Peas	U	110,000	1937	Peas	S	78,000,000
1935	Peas	U	64,000	1937	Peas	S	300,000,000

\*S = Satisfactory in nodulation tests; P = Poor in nodulation tests; M = Unsatisfactory in nodulation tests.

cells in the culture is unusually low, a fact, which when established, is also useful. Cultures with counts between these figures are of intermediate value.

In view of these results, it seemed that there should be no difficulty in checking to find whether failure to form nodules was due to insufficient numbers of bacteria. Table 2 shows that in culture A in 1932 approximately half the samples were incapable of nodule formation, and that in every case where nodulation failed, the number of legume bacteria was distinctly below 8,000,000 per pound of seed. In every case where nodulation occurred, there were more than 8,000,000 bacteria (apparently *Rhizobium*) per pound of seed by plate count.

To follow the relationship further in an attempt to improve the situation, specific suggestions were made to the manufacturer of this brand for increasing the number of legume organisms in the containers. To accomplish these changes (a) old cultures were removed from the market; (b) labels were printed to show the samples as good for only one year instead of two, thus preventing undue deterioration due to age; (c) the size of the containers was approximately doubled; (d) contamination was avoided, and (e) the entire surface of the agar was inoculated by spraying with a heavy suspension of the root nodule bacteria. After these changes were completed, samples of this brand produced consistent nodulation of host plants and the number of colonies by the plate count increased greatly.

Another brand (B) was satisfactory except for the alfalfa samples which were consistently poor in the nodulation tests. In Table 2 (1935), it will be noted that the numbers of what were apparently root nodule bacteria were high while nodule formation was unsatisfactory. Since the organisms present were apparently root nodule bacteria (by litmus milk and veal infusion tests), the only likely explanation seemed to be that the organisms had lost their nodule-forming ability. Storage of legume bacteria in inoculants may have a definite effect upon the laboratory characteristics of some cross-inoculation groups, as will be explained later, and it is only reasonable to assume, therefore, that such storage could affect the greenhouse performance as well.

The suggestion was made to the manufacturer, therefore, that a different strain of alfalfa bacteria of greater nodule-forming ability be used in making the cultures. A substitution was made, therefore, but as will be noted from Table 2 (1936) nodule formation was poor, although the numbers of bacteria (apparently *Rhizobium*) in the cultures continued to be high. The next year (Table 2, 1937), four strains of alfalfa bacteria of known nodule-forming ability from another source were used in the manufacturing process and all the samples produced nodules.

A third investigation was made when laboratory tests indicated that the inability of brand C to produce nodules was due to the death of the bacteria after the manufacture of the cultures. In testing, the observation was made that although the water used to wash the bacteria from the bottles became extremely turbid, indicating the presence of a large number of bacteria, actually, as judged by the plate count (Table 2) the number was low. In view of these observations,

the manufacturer made a study of the problem and the next year the cultures were prepared with openings in the caps to facilitate interchange of air through a porous material in the opening. Tests of approximately 25 samples of brand C since that time have failed to show the presence of a single culture incapable of nodule formation. The improvement in greenhouse performance, as in the case of culture A, was accompanied by a marked increase in the plate count.

The plate counts from these three brands, after the above corrections, are shown in Table 2 (1937). With one exception, all of the samples of these brands tested in 1937 produced nodules on their host plants. Table 2 shows clearly that the increased capacity for nodule formation by samples of brands A and C which had been low in numbers of nodule bacteria was accompanied by a distinct increase in the number of those organisms. Brand B in which numbers had not been deficient, naturally did not show such large increases.

During the course of these laboratory investigations, a situation occurred which was the exact opposite of that obtaining with the alfalfa samples of brand B. While with brand B colony development on agar plates was abundant and nodule formation was poor, recent instances have occurred in which no colonies were present on plates, while nodulation in the greenhouse was excellent, even when only 1/10 of the usual amount of inoculum was used.

These cases occurred with the soybean and cowpea inoculants of certain brands, and since it appeared that changes in the physiology of the bacteria had rendered them unable to grow upon the yeast-extract, mannitol agar frequently used for their cultivation, an attempt was made to devise a better medium, one which, if possible, could be prepared from pure chemicals. Accordingly, all plate counts during one season were made by using four media simultaneously. After a test of five or ten cultures, colonies were counted and new media were prepared upon the basis of the information thus secured. Best results were obtained with media containing l-aspartic acid, a growth-promoting substance for butyl alcohol producing bacteria (11); asparagin, useful in cultivation of typhoid bacteria (8); or sodium asparaginate, commonly used with soil bacteria (2). The first and the last of these have been studied most, and some of the counts obtained with the media in which one or the other occur are shown in Table 3.

It is evident from this table that the number of colonies of alfalfa, clover, pea, or bean bacteria is not improved greatly or consistently by use of these nitrogen sources. In the case of some of the soybean and cowpea cultures, however, the growth of the bacteria was entirely dependent upon the use of asparagin derivatives in place of yeast extract. It is expected that further work for development of a synthetic medium for *Rhizobium* will be carried on later.

#### DISCUSSION

The above investigations have shown something of the effect of the density of the legume bacterial population in an inoculant upon its capacity for nodule formation. It is apparent from Table 2 (A, B,



TABLE 3.—*Plate counts, yeast-extract agar vs. sodium asparaginate or l-aspartic acid agar.*

Type of inoculant	Plant group	Bacteria per pound of seed	
		Yeast-extract agar	Asparaginate or aspartic acid agar
Agar	Alfalfa	<b>180,000,000*</b>	131,000,000
Agar	Alfalfa	<b>270,000,000</b>	232,000,000
Agar	Alfalfa	200,000,000	<b>219,000,000</b>
Agar	Alfalfa	<b>79,000,000</b>	72,000,000
Agar	Alfalfa	150,000,000	<b>240,000,000</b>
Agar	Alfalfa	200,000,000	<b>246,000,000</b>
Agar	Clover	73,000,000	<b>93,000,000</b>
Agar	Clover	580,000,000	<b>638,000,000</b>
Agar	Clover	470,000,000	<b>880,000,000</b>
Agar	Clover	1,100,000	<b>1,600,000</b>
Agar	Clover	40,000,000	<b>55,000,000</b>
Agar	Clover	220,000,000	<b>272,000,000</b>
Sand	Clover	50,000,000	<b>69,000,000</b>
Sand	Clover	134,000,000	<b>166,000,000</b>
Sand	Clover	<b>146,000,000</b>	136,000,000
Agar	Peas	<b>200,000,000</b>	195,000,000
Agar	Peas	<b>60,000,000</b>	50,000,000
Agar	Peas	130,000,000	<b>151,000,000</b>
Sand	Peas	<b>4,000,000</b>	3,700,000
Sand	Peas	480,000	<b>610,000</b>
Sand	Peas	<b>6,400,000</b>	3,400,000
Agar	Soybeans	<b>270,000,000</b>	24,000,000
Agar	Soybeans	None found	<b>140,000,000</b>
Agar	Soybeans	None found	<b>220,000,000</b>
Agar	Soybeans	None found	<b>180,000,000</b>
Sand	Soybeans	23,500,000	<b>161,000,000</b>
Sand	Soybeans	21,000,000	<b>29,000,000</b>
Sand	Soybeans	13,000,000	<b>18,000,000</b>
Agar	Cowpeas	None found	<b>243,000,000</b>
Agar	Cowpeas	None found	<b>234,000,000</b>

\*The higher count in each case is indicated in bold faced type.

and C, 1937) that while in the more recent tests nodule formation was consistently good, the number of the bacteria in samples of legume inoculants was still variable. Table 2 shows that the number of legume bacteria in alfalfa cultures from brand A varied from 6 millions per pound of seed to 670 millions per pound with the most constant figure at about 200 millions. In the alfalfa series of culture B, upon the same basis, counts varied from 6 millions to 401 millions with the most constant figure near 50 millions. In the other cross-inoculation groups, the figures were about the same, as shown by cultures A and C.

At present, very few cultures made by the better companies contain so few bacteria that this factor can be suspected of causing failure in the nodulation tests. Nevertheless, it is possible that the 2 to 3% of cultures incapable of nodule formation which came from the more reliable factories in recent years were poor because an insufficient number of legume bacteria were present. Certainly, some of the low-count samples in Table 2 (1937) were in the range where the formation of nodules might be expected to be uncertain.

Since the variation in these products is so extreme, the question arises whether commercial cultures can be obtained that are more constant in the number of root nodule bacteria present. Apparently the only method now available for reducing the extreme variation is by mixing the contents of several samples. When fields of sufficient size are being seeded, the water used to wash the cultures from the containers might be mixed and the proper amounts per lot of seed withdrawn from the mixture.

The results of this investigation show that variation in numbers is a factor which must be considered in the manufacture and use of legume inoculants. Besides the extreme variation in numbers of bacteria in containers designed for use with uniform amounts of seed, there are cases where the proportion of bacteria actually capable of forming nodules upon their host plants vary widely from the usual range. Furthermore, it is known (5, 12, 13, 14) that the nitrogen-fixing capacity of different strains, even in the same cross-inoculation group, may vary widely.

In view of the above findings, it is apparent that for reasonably consistent nodule formation, cultures should carry on the average 80,000,000 to 200,000,000 bacteria per pound of seed they are to inoculate. In this way, the proportion of samples containing a sufficient number of bacteria for production of nodules will probably be high. These bacteria should have among them a large enough proportion of cells actually capable of nodule formation to cause infection to the desired extent. In addition, according to the results of the above investigations (5, 12, 13, 14), the strains used in the manufacture of the cultures should have the ability to fix relatively large amounts of atmospheric nitrogen in symbiosis with the plants for which they are intended.

### CONCLUSIONS

1. A study was made (a) to determine the number of individual legume bacteria necessary for the inoculation of individual seeds of alfalfa and clover, (b) to develop laboratory standards for judging whether cultures were deficient in numbers of nodule bacteria, and (c) to use these standards for improving the cultures that failed to produce nodules.

2. Comparisons of plate counts and plant counts of alfalfa and clover inoculants indicate that roughly between 5 and 40 bacterial cells are required for the inoculation of an individual seed.

3. Data from tests of more than 300 inoculants show that laboratory standards based upon these figures correlate quite well with results of nodulation tests except in cases where the bacteria have to a large extent lost their infective ability, or where the medium is not suited to the organisms which are being counted.

4. Cultures that carry fewer than 1,000,000 bacteria per pound of seed usually fail to produce nodules in the greenhouse; those which carry 8,000,000 or more (apparently legume bacteria) usually form nodules upon their host plants. Cultures with counts between these figures are of intermediate value, but usually form nodules.

5. Some of the brands which failed to produce nodules were studied to find whether they were deficient in the number of legume bacteria present. It was found that one (A) was consistently low in numbers of bacteria, a second (B) contained alfalfa organisms that had lost the ability to form nodules, and a third (C) had apparently developed a large number of organisms which had died later.

6. The manufacturers corrected these situations (a) by increasing the number of legume bacteria per culture, (b) by the use of strains of greater nodule-forming ability, and (c) by the use of a stopper which allows aeration of the culture and thus permits the bacteria to live.

7. Lack of growth in the laboratory by soybean and cowpea bacteria from legume inoculants capable of nodule formation was corrected when sodium asparaginate or l-aspartic acid was used as the nitrogen source in place of yeast extract.

8. The number of legume bacteria in the individual packages of a series of inoculants varies enormously.

9. Apparently the only way in which this extreme variation can be controlled at present is for the user to mix the wash water from several packages of inoculants and then to withdraw proportionate amounts for inoculation of definite amounts of seed.

10. For best performance inoculants should probably carry 80,000,000 to 200,000,000 nodule bacteria per pound of seed the culture is intended to inoculate. Such organisms should be high in nodule-forming ability and in capacity to fix atmospheric nitrogen in symbiosis with the host plant.

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## CROP PRODUCTION ON LAND BADLY DAMAGED BY WIND EROSION IN THE GREAT PLAINS<sup>1</sup>

CHARLES J. WHITFIELD<sup>2</sup>

DURING the past five years the effects of wind action on soils in the Great Plains have been brought to the attention of the people of this country by the yearly occurrence of numerous dust storms. At Dalhart, Dallam County, Texas, which is near the heart of the "Dust Bowl", there were 61 dust storms reported in 1935, 45 in 1936, and 60 in 1937. Another striking manifestation of the work of wind action in this region is the sand dune area which has developed in recent years as a result of cultivation, grazing, and drouth on lands where previously no dunes were present. At least 12 such sites are to be found in Dallam County alone, and numerous others occur in Texas, Colorado, Kansas, Nebraska, Wyoming, North Dakota, and South Dakota.

A sand dune area consists of two distinct parts, namely, the hard eroded land from which soil materials have been removed and the dunes proper. The former lies to the west and southwest, as well as between the dunes, and has been found eroded to depths of as much as 4 feet. The dunes themselves are large piles of sand ranging from 50 to 770 yards long, 30 to 50 yards wide, and from 2 to 30 feet in height.

Early in 1936 the Soil Conservation Service established a project to see whether such dune areas could be stabilized and whether they could be returned to utilization if this were done. Within a short time it was found that a great deal of sand movement was occurring on these areas, and that the size and height of the dunes, rate of wind movement, and condition of the soil material greatly influenced the amount of blowing. One small dune was found to have moved 155 feet during a 10-week period, while a much larger one advanced only 37 feet in 52 weeks.

### DUNE STABILIZATION

As is well known, a vegetative cover is the best means of preventing soil material from moving. To stabilize effectively the sand by the establishment of a cover, it first became necessary to decrease the height of the dunes to a point where they could be successfully planted. By utilizing the wind to blow away the very sand that it had built into dunes, it proved possible to lower them to the proper level. Three principal means were employed for this purpose, *viz.*, wind intensifiers, dragpole, and tractor and road grader.

Wind intensifiers of several types proved very efficient in moving sand, large gaps being dug out of the dune by the action of the wind and the sand carried out beyond the crest (Fig. 1). The use of such means to lower dunes did not prove to be practical, however, because

<sup>1</sup>Contribution from the Soil Conservation Service, U. S. Dept. of Agriculture, Amarillo, Texas. Received for publication January 31, 1938.

<sup>2</sup>Soil Conservationist.

too much manual labor was involved, both in setting up the intensifiers and in digging out those that were undermined and toppled over and became totally or partly covered by the moving sand during heavy windstorms.



FIG. 1.—Wind intensifiers made of boards and galvanized iron and placed on top of dunes. Foreground, badly eroded area; in background is a dune 26 feet high.



FIG. 2.—The drag-pole method showing pole and method of treatment used to break the crests of the dunes in order to facilitate sand movement. This method is more effective than others tried in utilizing wind action to lower dunes.

The drag-pole, an 8 by 8 inch pole of sufficient length to stretch from the crest of the dunes down the leeward slope to their base, was operated by hitching one or two horses to each end and dragging it along the sharp edge at right angles to the crest (Fig. 2). The drag-pole procedure is much more efficient than the wind deflector in that there is less hand labor, a greater area can be covered in a shorter time, and correspondingly larger amounts of sand can be moved. When the tractor and blade were used a wind channel was cut in the

dunes, parallel to the direction of the wind, by making one to three turns over the highest points, giving the wind a chance to move the

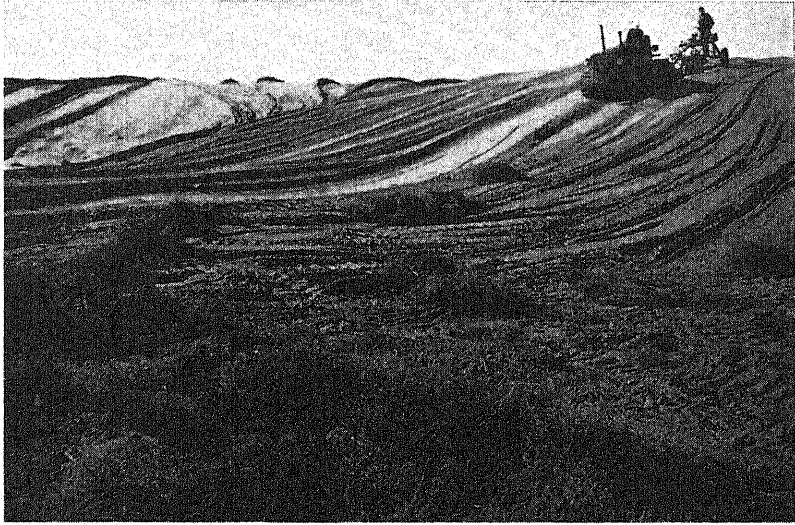


FIG. 3.—The tractor and grader method of cutting wind channels on one of the large dunes to accelerate lowering the dune.



FIG. 4.—Sand caught in lister rows on the treated dune area. When these furrows fill the land will be re-listed.

sand (Fig. 3). One 20-foot dune prepared for wind-blast action by this method was lowered to 5 feet during a 6-month period, thus putting it in condition for planting.



The principal method employed to prevent the sand moving from one dune to accumulate on another was deep listing on the eroded area. This procedure prevents more sand from accumulating on the dune and also catches the material blown off the dune. Re-listing was done over much of the area, and the soil, even that which was badly eroded, was mixed with sand and other wind-blown material to such an extent that it became feasible to plant most of it (Fig. 4).

#### VEGETATIVE COVER

In order to determine which crop species were more adaptable to the various soil and erosion conditions existing on the treated dune area of some 400 acres, the following practice was initiated: The field was first divided into four parts, each of which was subdivided into seven smaller units, each unit being planted to a different crop. Sudan grass, black amber cane, kafir, milo, broomcorn, hegari, and millet were used. The ordinary farm procedure in general practice throughout the region was used on the research area. The crops were listed and drilled, then planted the last part of May and early June. The amount of precipitation received on the sand dune area was above normal for May only and below average for the months of June through October, or nearly the entire growing season.

A comparison of the various species planted showed that broomcorn developed a better stand and produced a more vigorous growth over the entire area, individual plants ranging from a height of 18 inches in the poorer subsoils to 8 feet in the better soils. Sudan grass was second in importance, with black amber cane, hegari, and kafir corn next. Furthermore, observations indicate that broomcorn and sudan are more resistant to wind action than the other species. These two crops thus acquire greater significance in areas subject to severe wind erosion.

Plant response was measured in relation to soil and subsoil type. On areas where minor accumulations had occurred the best growth of all crops was secured. It was interesting to note that development was better here than on cultivated areas of virgin soils upon which the protective grass cover had been practically destroyed by wind blown materials. Fair to good stands developed on subsoils that had not been too deeply eroded wherever drifting sand had been caught in the furrows. In listed subsoil areas where no sand had drifted in, there was either a very poor stand or no growth at all. Apparently the sandy materials aid crop growth by making water or nutrients more available.

The actual field tests indicate that these badly eroded lands can be reclaimed for agricultural use in relatively short periods of time.



## EFFECTIVENESS OF SPRAYING WITH FERTILIZERS FOR CONTROL OF WEEDS ON ARABLE LAND<sup>1</sup>

B. N. SINGH AND K. DAS<sup>2</sup>

IN a previous communication (5),<sup>3</sup> a detailed study was made of the effectiveness of cultural treatments, such as varying the rate of seeding and the use of farmyard manure, on the control of weeds. In this paper are presented the results of experimentation on the relative efficiency of spraying with different fertilizer solutions in the control of annual weeds in cereal crops.

As a means of effective weed control, the value of fertilizers has been well recognized in recent years. Among the different fertilizers ammonium sulfate, sodium nitrate, calcium cyanamide, kainit, and a few others have received prominence in the direct suppression and control of annual weeds in cereal crops and grasslands.

The use of ammonium sulfate and of sodium nitrate applied in solution thus far appears to be limited to a few species only. Besides this limitation, opinion differs regarding the dosage and the degree of control obtained by each. Broadcasting under favorable conditions with calcium cyanamide or finely powdered kainit has given encouraging results with broad-leaved weed species. Experiments have further indicated that when mixed salts, such as calcium cyanamide and sylvanite or kainit are broadcast, an equally effective suppression accompanied by a higher yield of the crop is obtained. No knowledge exists, however, of the behavior of fertilizers in suppressing the weeds of arable land in the tropics where the problem is especially acute due to various favorable environmental and edaphic factors, *viz.*, high moisture content and high light intensity, which apparently favor a vigorous growth not only of the crops but also of the weeds.

Moreover, certain weeds seem to have a close correlation with the fertilizers according to their nutrient requirements. There is a general tendency of the nitrogenous manures to encourage weed growth while minerals seem to behave otherwise. Studying the influence of manuring on the weed flora of arable land, Warrington (8), on the other hand, has observed that the cumulative effect of long-continued manuring is of secondary importance except in certain instances of serious deficiency in the soil, such as lack of nitrogen or exhaustion of the minerals induced by prolonged application of ammonium salts only.

It thus appears that the influence of fertilizers in suppressing various species of weeds is by no means clear. A quantitative study of weed control by different fertilizers sprayed singly or in different combinations along with a study of their nutrient effect on the yield of the crop—the subject of the present study—should thus be of immense value. During the course of the present experiments, the

<sup>1</sup>Contribution from the Institute of Agricultural Research, Benares Hindu University, Benares, India. Received for publication February 11, 1938.

<sup>2</sup>Director and assistant, respectively.

<sup>3</sup>Figures in parenthesis refer to "Literature Cited", p. 473.

action of the fertilizers has been mainly judged by the killing effect on the growing tissue of the plant species resulting from the condition of plasmolysis set up in the plant cells by the greater osmotic concentration of the fertilizer solution. The difference in the growth habit, unequal age, and morphological adaptation of the two is taken advantage of in determining the relative liability to injury from a fertilizer solution. In the event of the injury not having proceeded far enough to kill the weeds, estimation is made of the extent to which the growth of the weed is checked and the extent to which the crop, receiving an additional filip from the plant food thus supplied, keeps the weeds under suppression by reason of its increased growth.

#### METHOD OF EXPERIMENTATION

Altogether eight treatments, including the control (Table 1), were selected to test their relative effectiveness in the suppression of annual weeds abounding in wheat fields. The fertilizer treatments may conveniently be arranged in three main groups as follows:

A. Single fertilizers:

1. Ammonium sulfate
2. Sodium nitrate
3. Potassium sulfate
4. Superphosphate

B. Combination of two fertilizers:

1. Ammonium sulfate + potassium sulfate
2. Ammonium sulfate + superphosphate

C. Combination of three fertilizers:

1. Ammonium sulfate + superphosphate + potassium sulfate

The treatments have been so selected that information may also be obtained as regards the nutritional response of the crop to spraying with fertilizer solutions containing one or a combination of two or of all three important plant food elements. In the mixed sprays ammonium sulfate has been a constant ingredient because of its apparent value in the control of weeds and in giving a fillip to the growth of the crop.

Each treatment was replicated five times in randomized plats of 1/50 acre arranged in five blocks in a field with a history of uniform crop production. The wheat seed (Pusa 4) was well cleaned so that no weed seeds were introduced through that source.

Fertilizers of a known dosage (Table 1) were applied at the rate of 100 gallons per acre with a knapsack sprayer. The spraying was done when the weeds were in the young seedling stage, i. e., when the crop was hardly more than 6 inches in height and active tillering had not yet begun. The parabolic nature of the changing density of weed flora (7) necessitates their early reduction in order to enable the crop to have a good stand.

In the course of a detailed quantitative study it was observed that among the annual weeds found in local wheat fields during the season, *Chenopodium album* and *Anagallis arvensis* have a more abundant distribution (6). This facilitated the collection and the subsequent analysis of the data where random samples had to be taken. The test of efficiency of the treatments employed has, therefore, been intentionally confined in the present paper to the data on the control of these two weed species only.

To determine both the degree of weed infestation and the control obtained by the various treatments, counts of the number of individuals of the above two weed species were made in a set of 20 random but pegged samples of 1 square foot quadrats in each plot before the spraying and three weeks after so that the partially injured plants may have sufficient time to recover.

Square quadrats were selected since in a previous study (5) such a form had been demonstrated to be more suitable than strips of the same size. A smaller unit was used, however, in these studies with a view to minimizing labor since a large number of counts had to be made. The difference between the two counts gave the degree of control obtained. The grain yield was also recorded to compare the effects of the treatments on the yield of the crop.

### STATISTICAL ANALYSIS OF THE DATA<sup>4</sup>

Since the variance of the estimates of density (number of individuals per square foot) is discontinuous, statistical computations to compare the significance of the different treatments on the reduction in weed density have been confined to the square roots of the number of individuals in unit area (1).

The covariance method of statistical analysis has been shown in recent years to be of considerable value in correcting yields of both annual and perennial crops in successfully removing local differences by utilizing previous yield records of individual plots (2, 4). This method has further been suggested (3) to correct yield for uncontrolled inequalities arising early in an experiment and of analyzing the effects of developmental factors on yield. Analysis of covariance has also been used to determine the relation between the morphological plant character and lodging in cereals (2).

The covariance method of analysis has been resorted to in order to adjust the mean square roots of the densities after spraying ( $Y$  variable) for the other variable ( $X$ ), i. e., mean square root of density before spraying, since it is to be expected that the density after spraying is closely correlated with the original density. Analysis of variance and covariance, analysis of adjusted variance of densities, and the corrected density after spraying of the two weed species are shown in Tables 2 to 5.

The residual correlation between the densities before and after spraying is significantly high (+ 0.78) in *C. album*, indicating that the two densities are closely associated. The error regression coefficient, eliminating the influence of the treatments and the soil differences, is 1.863. Taking advantage of the relation  $(Y - \bar{Y}) = 1.863 (X - \bar{X})$ , the uncontrolled variations arising early in the experiment are reduced and the precision of the final results is enhanced. Utilizing the mean covariance, improvement in efficiency is also brought about by reducing the residual variance. The corrected square roots of densities of *C. album* after spraying are shown in Table 4.

In the case of the other weed species, *A. arvensis*, the residual correlation is low (+ 0.29) showing a poor association of the two densities. Error regression coefficient is also 0.2976. The use of this method has therefore not been of much help in correcting the final estimate of density (Table 4).

<sup>4</sup>Our thanks are due to Prof. P. C. Mahalanobis of the Statistical Laboratory, Calcutta, for the useful suggestions in the statistical analysis of the data.

## RESULTS

## DEGREE OF CONTROL

An examination of the data (Tables 1 to 5) on the degree of control obtained by the various treatments indicates that among the single fertilizer sprays the two nitrogenous fertilizers, ammonium sulfate and sodium nitrate, gave significantly higher control of both weed species than either potassium sulfate or superphosphate. There is no significant difference, however, in the herbicidal effect between these two nitrogenous fertilizers, both showing nearly the same degree of

TABLE 1.—Treatments and quantities of fertilizers applied per plat and per acre and the degree of control obtained.

Treatment No.	Treatments	Dosage		Percentage of control obtained	
		Lbs. per plat	Cwt. per acre	<i>C. album</i>	<i>A. arvensis</i>
T <sub>1</sub>	Control	—	—	—	—
T <sub>2</sub>	Ammonium sulfate + potassium sulfate + superphosphate	2.5 + 2.5 + 2.5	3.35	73.94	76.26
T <sub>3</sub>	Sodium nitrate	5	2.24	55.51	66.53
T <sub>4</sub>	Superphosphate	5	2.24	33.36	43.56
T <sub>5</sub>	Potassium sulfate	5	2.24	41.36	42.36
T <sub>6</sub>	Ammonium sulfate	5	2.24	56.96	65.9
T <sub>7</sub>	Ammonium sulfate + potassium sulfate	2.5 + 2.5	2.24	63.53	68.14
T <sub>8</sub>	Ammonium sulfate + superphosphate	2.5 + 2.5	2.24	61.74	62.9

TABLE 2.—Analysis of variance and covariance of the square roots of densities of *C. album* and *A. arvensis* before and after spraying.

Variance due to	D. F.	S. S. before spraying X <sup>2</sup>	S. S. after spraying Y <sup>2</sup>	Sum of products (covariance) XY	Correlation coefficient r	Regression coefficient b
<i>C. album</i>						
Block.....	4	2.52	1.04	—	—	—
Treatment..	6*	14.89	167.96	41.68	0.83	—
Error.....	24	19.09	107.52	35.57	0.78	1.863
Total (treatment + error).....	30	33.98	276.52	77.25	—	—
<i>A. arvensis</i>						
Block.....	4	4.68	1.96	—	—	—
Treatment..	6*	0.41	84.748	4.18	0.709	—
Error.....	24	9.44	15.14	2.81	0.24	0.2967
Total (treatment + error).....	30	9.85	99.89	6.99	—	—

\*Degrees of freedom for treatments are 6 since one treatment (control) is not taken into consideration in this analysis.

TABLE 3.—*Analysis of variance of the adjusted square root of densities after spraying of C. album and A. arvensis.*

Variance due to	D. F.	<i>C. album</i>			<i>A. album</i>		
		Ad-justed S. S.	Ad-justed M. S. S.	Ratio of vari-ance	Ad-justed S. S.	Ad-justed M. S. S.	Ratio of vari-ance
Treatment....	6	58.51	3.75	5.44	80.63	13.44	21.67
Error.....	23	41.25	1.793	—	14.30	0.62	—
Total (treat-ment+error)	29	99.76	11.543	—	94.93	14.06	—

TABLE 4.—*Mean square roots of densities per 1 square foot of C. album and A. arvensis before and after spraying.*

Treat-ment No.	<i>C. album</i>			<i>A. arvensis</i>		
	Mean sq. root of density before spraying	Mean sq. root of density after spraying	Corrected mean sq. root of density after spraying	Mean sq. root of density before spraying	Mean sq. root of density after spraying	Corrected mean sq. root of density after spraying
T <sub>2</sub>	5.63	2.82	3.27	3.49	1.66	1.66
T <sub>3</sub>	6.09	4.14	3.73	3.53	2.04	2.03
T <sub>4</sub>	5.90	4.79	4.73	3.52	2.64	2.63
T <sub>5</sub>	5.93	4.52	4.41	3.52	2.69	2.68
T <sub>6</sub>	5.89	3.85	3.81	3.49	1.99	1.99
T <sub>7</sub>	5.95	3.56	3.41	3.48	1.94	1.95
T <sub>8</sub>	5.69	3.51	3.84	3.50	2.08	2.08

control. This observation is contradictory to the generally accepted view that sodium nitrate is inferior to ammonium sulfate and its use therefore limited as an effective stimulant to enable a vigorous growth of the crop and thereby suppress the competing weeds.

Spraying with the non-nitrogenous fertilizers, such as potassium sulfate and superphosphate, gave the least control of both weed species for all the treatments. The data further indicate that the differences between the two treatments is also not significant, although with *C. album* potassium sulfate gave a higher degree of control while in the case of *A. arvensis* superphosphate appeared most efficient. (See Figs. 1 and 2.)

With both weed species, spraying with a combination of two fertilizers, ammonium sulfate and superphosphate or ammonium sulfate and potassium sulfate, did not appear to enhance very much the herbicidal efficiency of the two nitrogenous fertilizers, although the combinations did give significantly better results than either potassium sulfate or superphosphate alone. Also, there was no significant difference between these two treatments, although in general the combination of ammonium sulfate with potassium sulfate seemed to give better results than the addition of superphosphate to ammonium sulfate (Table 5).

TABLE 5.—Significance of the adjusted mean square roots of densities after spraying.\*

Treatment No.	T <sub>3</sub>		T <sub>4</sub>		T <sub>5</sub>	
	<i>C. album</i>	<i>A. arvensis</i>	<i>C. album</i>	<i>A. arvensis</i>	<i>C. album</i>	<i>A. arvensis</i>
T <sub>2</sub>	*	+	+	+	+	+
T <sub>3</sub>			+	+	+	+
T <sub>4</sub>					*	—
T <sub>5</sub>						
T <sub>6</sub>						
T <sub>7</sub>						
	T <sub>6</sub>		T <sub>7</sub>		T <sub>8</sub>	
	<i>C. album</i>	<i>A. arvensis</i>	<i>C. album</i>	<i>A. arvensis</i>	<i>C. album</i>	<i>A. arvensis</i>
T <sub>2</sub>	+	+	*	+	+	+
T <sub>3</sub>	*	*	*	*	*	*
T <sub>4</sub>	—	—	—	—	—	—
T <sub>5</sub>	—	—	—	—	—	—
T <sub>6</sub>			*	*	*	*
T <sub>7</sub>					*	*

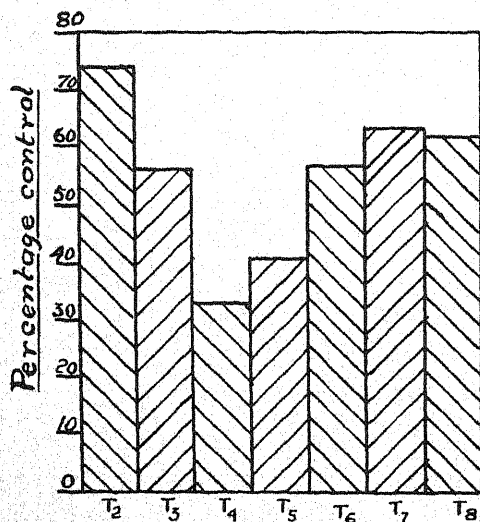
\*Explanation of signs:

+denotes that the density in the vertically indicated treatment is significantly greater than the horizontally indicated one.

—denotes the reverse, i.e., it is significantly less.

\*denotes that the difference is insignificant.

The most effective treatment was a combination of ammonium sulfate, superphosphate, and potassium sulfate where a consistently high degree of control was obtained for both weed species. Comparing the mean square root of densities after spraying (Table 5), it is

FIG. 1.—Degree of control of *C. album* obtained with different fertilizer treatments.

observed that in the case of *C. album* this treatment gave significantly better result than all the other treatments except sodium nitrate and the combination of ammonium and potassium sulfates, but on the contrary, spraying with the combination of the three fertilizers gives, in the case of *A. arvensis*, significantly better result than any of the other treatments. A range of 10 to 30% increase in the degree of control over the other treatments is obtained by spraying with this mixture.

Excluding the combinations of sulfate of am-

monia and superphosphate or the double sulfates of ammonia and potash, a slightly higher degree of effectiveness is obtained by all the other treatments in the control of *A. arvensis* than in the case of *C. album*. Though the increase is not always consistent, the difference of such a behavior may be accounted for by the relative hardness and morphological peculiarities of the two weed species. *C. album* besides having leaves with waxy hairs which make wetting and penetration of the solution difficult, also appears to be more resistant than *A. arvensis*, resulting therefore in a slightly higher degree of control of the latter.

The interaction of the factors bringing about the differential behavior of the spray solutions is not clearly defined. The unequal osmotic concentration of the different solutions, the quantity of solution adhering to the surface of the tissue for varying lengths of time, and the relative toxicity of the different ions are factors which seem to be partly responsible for the final result.

#### EFFECT ON YIELD

Analysis of the data on the effect of these sprays on the yield of the crop infested indicates that the layout and the experiment have been highly significant at 1% level of significance (Table 6). Examination of the data in Table 7 reveals that all the treatments gave significant increases in yield as compared to the mean yield of the control plots.

TABLE 6.—Analysis of variance of the yield of grain.

Variance due to	D. F.	Total S. S.	Mean S. S.	Ratio of variance
Block.....	4	6.02	1.505	—
Treatment.....	7	70.714	10.102	19.964**
Error.....	28	19.74	0.506	—
Total.....	39	96.474	12.113	—

Of all the treatments, the highest increase in yield was obtained from the mixed spray of ammonium sulfate, potassium sulfate, and superphosphate with an increase of 19.78% over the control (Fig. 3). Ammonium sulfate in combination with potassium sulfate gave the next best result. The lowest increase was obtained from potassium sulfate with only 6.82% increase. The treatments arranged in de-

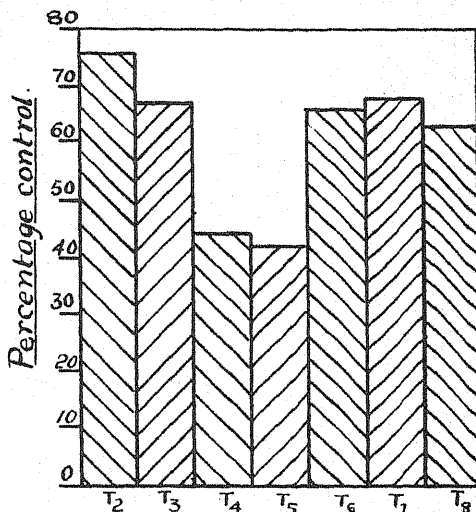


FIG. 2.—Degree of control of *A. arvensis* obtained with different fertilizer treatments.

TABLE 7.—Mean yield of grain in pounds per plot for the treatments.

Treatments	Mean yield in pounds per plot	Percentage increase from the control mean
T <sub>1</sub> (control).....	20.22	—
T <sub>2</sub> .....	24.22	19.78
T <sub>3</sub> .....	22.58	11.67
T <sub>4</sub> .....	21.78	7.71
T <sub>5</sub> .....	21.6	6.82
T <sub>6</sub> .....	23.44	15.92
T <sub>7</sub> .....	23.98	18.59
T <sub>8</sub> .....	23.28	15.13

Critical difference required for significance between the treatment means at  $P=0.01$ ..... 0.90

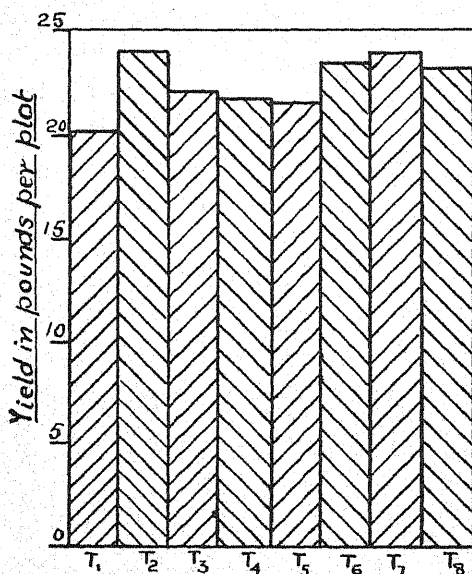


FIG. 3.—Yield of wheat in pounds per plot under different fertilizer treatments for weed control.

scending order of increase over the control were as follows: Ammonium sulfate, potassium sulfate and superphosphate; ammonium sulfate and potassium sulfate; ammonium sulfate; ammonium sulfate and superphosphate; sodium nitrate; superphosphate; and potassium sulfate.

The difference between the treatment where the highest increase in yield was obtained and any one of the treatments with ammonium sulfate alone or in combination with either potassium sulfate or superphosphate was not significant. Similarly, no significant difference was traced between ammonium sulfate alone and its use in combination with either superphosphate or

potassium sulfate. No significant difference was traced between the effects of potassium sulfate and superphosphate.

It has not been possible to trace a relationship between the reduction of weed density and the increase in the yield of the crop since the latter may result from the combined effect of the reduction in intensity of weed competition and the extra nutrition added in the fertilizers. There are indications, however, that the association of weeds does not necessarily always result in a poor yield of the crop. The average increase in yield in the plots treated with the mixture of ammonium sulfate and superphosphate was 19.78% of the mean yield in the control plots, while the mean weed density of the two weed species,



in the control plats was, roughly, 3.5 and 4.5 times, respectively, of the number of individuals found in the plats sprayed with this mixture. Allowing for the proportionate share of the manurial effect in the increase in grain yield, it may be inferred that a large degree of increase cannot be attributed to the indirect effect of reduction in the density of weeds. It may also be argued, on the other hand, that the two weed species are not serious competitors and hence do not significantly disturb the nutrient level of the crop.

Observations on the relative amount of crop injury by the spray solutions indicate that the crop did not suffer very much except for a slight scorching in some cases soon after spraying. Such damage was only temporary and did not affect the final yield. Apart from the morphological peculiarities that may determine the selective effectiveness of the spray, the damage may also be counterbalanced by the relative growth rates of the two. Observations on the competitive efficiency of the weeds and the crop, which will be discussed in a later paper, show that the relative growth efficiency of the crop is generally much higher than that of the common weeds abounding in it. This physiologic potentiality of the crop carries it away beyond weed competition so that a clean field is obtained in the end.

#### SUMMARY AND CONCLUSION

Replicated field experiments have been carried out to determine the effectiveness of ammonium sulfate, sodium nitrate, potassium sulfate, and superphosphate sprayed singly or in different combinations in controlling annual weeds abounding in a wheat crop (Pusa 4).

The relative significance of the different treatments was judged by comparing the mean square roots of weed densities after spraying. Covariance method of statistical analysis has been applied to improve the precision of the experiment and to adjust the mean square roots of densities after spraying for the original weed density before spraying.

The results with different treatments varied between 33% and 73% control of *C. album* and 42% to 76% of *A. arvensis*.

The treatments also gave significant increases in the yield of grain as compared to the control plats. The increase for the different treatments varied from 7% to 20% of the mean value of the control plats.

The combination of ammonium sulfate, superphosphate, and potassium sulfate besides giving the best degree of control for both weed species also gave the maximum yield among all the treatments.

These observations indicate that spraying with fertilizers may be advantageously used for the combined effect of reducing the weed density in cereal crops and of increasing the yield of the grain.

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# DISTRIBUTION OF SUGARS, ROOT ENCLOSED, IN THE SOIL FOLLOWING CORN AND SORGHUMS AND THEIR EFFECTS ON THE SUCCEEDING WHEAT CROP<sup>1</sup>

JOHN P. CONRAD<sup>2</sup>

STRONG competition for available plant nutrients, particularly nitrates, between the growing crop following sorghums and the soil micro-organisms living on the sugars and possible other carbonaceous residues of the dead sorghum roots was suggested (1)<sup>3</sup> several years ago as one of the causes of the injury of sorghums to succeeding crops. More recently, the writer has reported (5) analyses of roots of sorghums showing at maturity total sugars on the basis of dry organic matter, varying from 15 to 55%, and roots of corn (a crop causing little or no injury) ranging from less than 1 to about 4.5%. Assuming that the amounts of roots were the same for the two crops, these data give added support to the hypothesis that the injury is caused in part by the sugar residues.

After sorghums, the good growth of inoculated legumes, and the response of nonlegumes to nitrogenous fertilizers, in both nitrate and ammonium forms (2, 3) cast considerable doubt on the presence of "toxic bodies" originating from the decomposition of the sorghum residues as the cause of the sorghum injury, but they suggest rather an insufficiency of nitrogen as a major part, at least, of its cause. Two factors, sorghum plant absorption, unusually complete perhaps by virtue of the vigorous growth of the sorghums, and competitive absorption by soil micro-organisms, undoubtedly greatly stimulated by feeding on the dead sorghum plants later, may contribute to this dearth of nitrogen available to the next crop.

So far in the field it has been difficult to distinguish between these two factors as they both tend to decrease yields of succeeding non-leguminous crops. This paper presents data on the effects of the decay of the sorghum residues themselves, first by giving figures on the amount and distribution of sugars left in the soil by the sorghum crop and then by comparing the areas of high residual sugars in the soil with those of decreased crop yields.

In writing of the residual sugars left in the soil in this paper it is assumed that the sugars are enclosed within living or dead roots, and not free in the soil, as in the latter condition they would without a doubt disappear rapidly because of microbial activity.

## LABORATORY TECHNIC

In determining the amount of sugar left in the soil by any crop, at least two methods of procedure are possible. In one, the roots could be separated from a

<sup>1</sup>Contribution from the Division of Agronomy, University of California, Davis, Calif. Received for publication February 22, 1938.

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<sup>3</sup>Reference by figures in parenthesis is to "Literature Cited", p. 483.

weighed lot of soil, washed free of adhering soil particles, dried, weighed, and then analyzed for sugars. In the practical use of this method undoubtedly considerable losses of roots and rootlets would occur, and much sugar might be lost in the wash water as many of the sorghum roots are turgid, brittle, and easily broken, exposing the cell contents to rapid diffusion. This method might give comparable results between different varieties of sorghums and between different crops, but absolute results would probably be low because of mechanical and solution losses.

A more direct method was decided upon, namely, to determine the sugars by direct extraction of the soil. Consequently, samples of soil containing the roots of the crop in question were secured from the field (by different methods to be described later), quickly brought to the laboratory, covered with 70% ethyl alcohol, boiled for half an hour under a reflex condenser, stoppered, and stored for later analysis. The method of analysis consisted of throwing the soil and roots on a Buchner funnel and leaching each sample with about 12 successive portions (about 150 ml. each) of hot 70% ethyl alcohol. The leachings were transferred to flasks and the alcohol removed by distillation under much reduced pressure until an alcohol-free aqueous solution of the sugars was secured. This solution was cleared with neutral lead acetate and "de-leaded" with di-sodium phosphate. After diluting the cleared extract to a definite volume, an aliquot was taken for the total sugar determination which was made by the colorimetric picric acid method of Willaman and Davison (8). This method allowed fairly accurate sugar determinations to be made on small amounts of much condensed extracts from considerable quantities of soil ranging from 200 to 1,500 grams per sample.

#### EXPERIMENTAL RESULTS

Table 1 shows the lateral and vertical distribution with respect to the crop rows of total sugars left in the soil by sorghum and corn plants, the soil samples being taken with a soil tube (7). In every case, soil under sorghums contained more sugar than under corn. The soil under one variety of corn, Orange County Prolific, which bore no normal ears, was considerably higher in sugars than that under King Philip Hybrid corn where normal ears developed. These findings are consistent with more numerous analyses of corn and sorghum roots recently published (5). Most of the sugars are concentrated near the crowns of the plants. These findings are in line with the distribution of roots found by digging into the soil beneath these crops.

In 1935, King Philip Hybrid corn and Honey sorgo were grown for the special purposes of these and other studies. The culture of these crops was previously described more in detail (4). Much larger samples of soil were taken in 1935 than in 1934 in order to determine the amount of sugar per unit weight of soil more accurately, especially where there were smaller amounts present. It will be observed, as shown in Table 1, that again the Honey sorgo had a much larger concentration of sugar beneath it than had the King Philip Hybrid corn. Under the sorgo there was an indication of an increase in sugars from the second to the fourth foot that did not occur with the Indian corn. No adequate explanation for this is offered, except that there might be a chance increase in other organic compounds in the soil which would affect the picric acid and cause its reduction. The amounts

involved, however, are probably not high enough, even if they were sugars, to cause any appreciable effect on subsequent plant growth.

TABLE 1.—*Lateral and vertical distribution of total sugars as sucrose in parts per million of dry soil in relation to the crowns of the respective crop rows.*

1934 samples:*	Dwarf Yellow Milo			Dwarf Yellow Milo		
Sorghum varieties.....	6 in.			36 in.		
Spacing between rows.....						
Lat. dist., in.†.....	0	1½	3	0	9	18
Depth, 1st foot.....	259	29.1	10.8	278	17.6	1.5
Depth, 2nd foot.....	5.7		6.2	1.7		1.8
Varieties, 36 in. spacing....	Honey Sorgo			White Durra		
Lat. dist., in.†.....	0	9	18	0	9	18
Depth, 1st foot.....	232	15.0	11.8	650	14.2	14.5
Corn varieties.....	King Philip Hybrid			Orange County Prolific		
Condition (36-in. spacing).	Normal ears			No normal ears		
Lat. dist., in.†.....	0	9	18	0	9	18
Depth, 1st foot.....	2.3	2.4	2.1	22.3	5.5	4.9
1935 samples:*	King Philip Hybrid			Honey Sorgo		
Crop (42-in. spacing).....	Nearly mature			Milk stage		
Condition of seed.....						
Lat. dist., in.†.....	0	11	22	0	11	22
Depth, 1st foot.....	3.2	2.5	—‡	443	5.6	4.4
2nd foot.....	1.7	2.7	—‡	1.5	2.7	1.5
3rd foot.....	1.3			3.4		
4th foot.....	1.8			15.5		

\*Samples were taken with a soil tube (7).

†Lateral distance from center of row.

‡Sample lost.

It was realized that the analyses in Table 1 might be low as representing conditions supposedly being sampled. During the process of sampling with the soil tube the shearing of the roots by the tube might cause some squeezing out of the plant sap from the roots. Losses from this factor are considered to be rather low, however. Another possible reason for low results would be the unconscious effort of the operator to secure average conditions and therefore his reaction would be to avoid sampling down through the crowns of the plants in securing the cores for compositing. It is thought that if these results are low this factor would be the most important one involved. Again, in the extraction of the sugars with alcohol, because of the roots being more or less whole, extraction might be incomplete. In studies for Tables 2 and 3, the roots, after the usual extraction, were mechanically separated from the soil as completely as possible and subjected to the usual grinding and further extraction. In the samples in which the greatest quantities of roots occurred, incomplete extraction was shown, but the sugars thus recovered amounted to only about 10% at the most of the sugars already extracted.

In connection with the data reported in Table 2, the soil was carefully spaded away to a depth of 1 foot from an upright prism of soil,

6 inches wide (3 inches on each side of a sorgo plant) extending at right angles to and across the row. A wooden frame was put over this prism in such a way that it could be slid back and forth, closer to or further from, the crop row. By using the wooden frame as a guide, the prism was further prepared for sampling by shearing away with a spade practically all that remained on one side of the row. Each soil sample, as a vertical spade slice to a depth of 1 foot, was placed in a 2-liter Erlenmeyer flask and brought to the laboratory for boiling and analysis. Subsequently, and in succession, slices of soil 6 inches long, 12 inches deep, and approximately 1 inch wide, were taken in order from the row center, out towards the center of the space between rows, across another crop row which bordered on a fallow strip, and into the fallow to a distance of approximately 60 inches. As shown in Table 2, this last sample gave a reading of 6.3 p. p. m. total sugars

TABLE 2.—*Lateral distribution of total sugar as sucrose in parts per million (p.p.m.) of dry soil in the surface foot under mature Honey sorgo as found in a series of vertical soil prisms at various lateral distances from the center of the inner crop row.*

Lat. dist., in.*	0.5	0.5	1.5	2.5	5	9	14	22	26
Sugars, p.p.m.	4,750†	3,850†	135	292	5.9	7.5	9.9	7.6	26.8
Lat. dist., in.*	30	36	38.5	40	41.25	46	53	102‡	
Sugars, p.p.m.	25.0	13.3	158	374	3,000	290	20.8	6.3	

\*Lateral distance east of inner row center. Center of outer row at 42.0 inches.

†Includes remains of 2½ inch stubble.

‡Sixty inches into fallow; therefore expected to contain no or but few roots.

as sucrose. This probably represented not sugars alone but other organic materials in the soil as well and could be considered as a control or blank on the field soil for the methods used. Any considerable amounts above this figure then would represent sugars actually present in the roots within each sample of the soil. Considering that the outer row adjoining the fallow is at "the lateral distance of 42 inches" in Table 2, it is evident that the sugars in amounts greater than 100 p.p.m. are within a relatively few inches on either side of the row centers and do not extend very far into the spaces between rows. In Fig. 1 A the amounts of sugars as ordinates are plotted logarithmically. The differences in actual sugar percentages are thus very much minimized graphically.

After investigating the soil profile vertically exposed in securing the samples for Table 2, it seemed desirable to get some idea of the vertical distribution of total sugars within the soil. Consequently, a series of 1-inch horizontal soil layers in a column of soil (containing one sorgo plant) 6 inches lengthwise of the row and 4 inches on either side of it, were secured. All of the soil from the surface to 11 inches deep in this column was secured in these successive samples, which were later analyzed, the results being reported in Table 3, and represented graphically in Fig. 1 D, where the amounts of sugars as sucrose are again shown logarithmically.

TABLE 3.—Vertical distribution of total sugars as sucrose in p.p.m. of dry soil under mature Honey sorgo as found in consecutive 1-inch depths in a column of soil 6 inches lengthwise of the row and 4 inches on each side of it.

Depth, inches. . . . .	1st	2nd	3rd	4th	5th	
Sugars, p.p.m. . . . .	12,710*	3,150	1,600	1,520	400	
Depth, inches. . . . .	6th	7th	8th	9th	10th	11th
Sugars, p.p.m. . . . .	20.0	37.2	89.2	14.1	7.8	8.9

\*Includes about 2½ inch stubble extending above the soil surface.

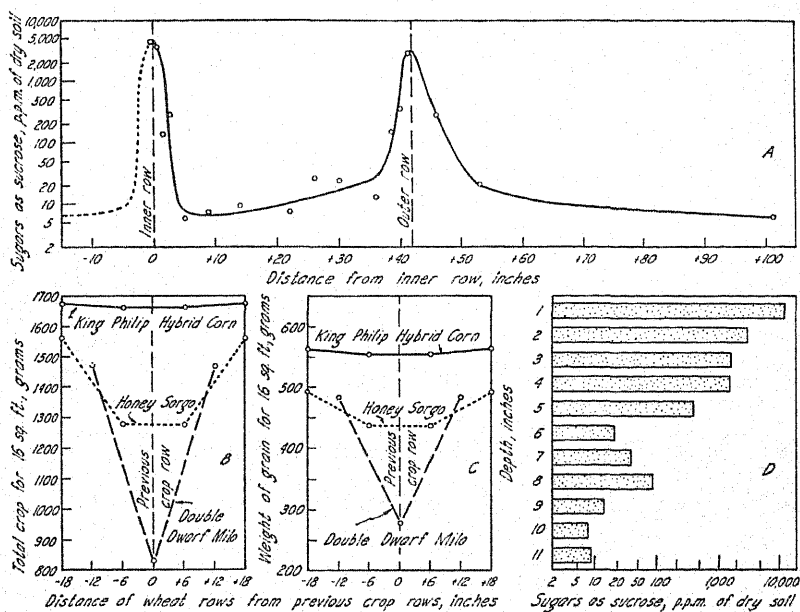


FIG. 1.—Distribution of sugars in the soil and associated injury to crop yields. A, Lateral distribution of sugars (plotted logarithmically) across two sorgo rows and into the adjoining fallow. B, Total yields of rod rows of wheat as related to distance from previous rows of corn, sorgo, and milo. C, Corresponding grain yields. D, Vertical distribution of sugars (plotted logarithmically) in a column of soil beneath a sorgo row.

From a consideration of the analyses in Table 3 alone, it might be assumed that there was considerable variation due to sampling errors. In other words, the 4th inch depth might have been considered to contain less than it did. Again, the 7th and 8th inch depths showed considerably more sugar than the 6th inch depth. It is believed, however, that additional sampling would not materially change this order. At about 4 inches in depth the bottom of the mulch occurred. Here the roots would have encountered considerably greater resistance to penetration. In an examination of sorghum roots in the row it is often possible to pull on one plant and partially pull up the roots

of the adjoining one which have entwined with the roots of the first in the furrow made by the shoe of the planter. In other words, roots developing from the crown in the later stages of the growth of the plant may move laterally several inches in this planter shoe furrow before finding a crack or other path of least resistance to move into the deeper subsoil. Again, at the 7th or 8th inch depth a plow sole occurred, representing the usual depth of plowing. This layer, somewhat compacted, undoubtedly caused the roots to accumulate above it to some extent before finding places sufficiently weak to allow easy penetration.

After the crops were harvested, shallow furrows 1 foot apart, parallel to the crop rows, were made as for planting nursery row rows of grain and were planted to White Federation wheat on November 21, 1935. After maturity these rows were harvested in the usual way on June 20, 1936, yields obtained, and reported in Table 4. As no intervening seedbed preparation was given to the soil after harvesting of the corn and sorgho, except for the furrowing-out and as the nearest furrows varied from 3 inches to 9 inches from the crowns of the previous crop plants, the sugars in the roots, if they caused injury to the wheat plants, might be expected to affect the two rows immediately adjacent to the previous crop row. For that reason the two center rows adjacent to the previous crop row were averaged as the "affected rows" and the yields of the total crop and of the threshed grain were compared with the rows adjacent to them, one on either side. This gave a paired comparison suitable for the use of Student's method for statistical evaluation. With all of the rows as grown in these plats under conditions as described, seven comparisons for each of the crops, corn and sorgho, were secured. The average yields of the wheat rows, adjacent to the previous Honey sorgho row, were cut down as compared to the rows immediately adjacent and this reduction was statistically significant as reported in Table 4.

TABLE 4.—*The effect of previous crop rows of corn and sorghum in decreasing the yields of 16-foot rows of White Federation wheat.*

Previous crop	Number of pairs	Part of crop	Yield in grams per 16-foot row				
			Affected rows		Av. of 2 control rows*	Decrease	Student's odds (6)
			No.	Av. yield			
King Philip Hybrid corn	7	Total Grain	2†	1,662	1,678	16	3.75
			2†	555	564.5	9.5	14.6
Honey sorgho. . . . .	7	Total Grain	2†	1,280	1,562	282	5,000
			2†	436	493	57	450
Double Dwarf Milo. . . .	8	Total Grain	1‡	836	1,474	638	10 <sup>5</sup>
			1‡	278	484	206	3,000

\*Two unaffected rows, one on either side of the one or two affected rows.

†Two affected rows adjacent to previous crop row.

‡One affected row over previous crop row.



In the lower part of this table are given data with regard to Double Dwarf milo. This crop was grown on unirrigated land in spacing trials with grain sorghum conducted by Professor George W. Hendry, and the land turned over to the writer for experimentation after harvest. To clear the land for the wheat crop, the milo plants were cut off rather shallowly below the surface with a plow and removed, resulting, undoubtedly, in the removal of a portion of the sugars. This operation, however, enabled the rows of wheat to be placed immediately over the previous crop row. As before, shallow furrows were made 1 foot apart parallel with the previous crop rows and White Federation wheat seeded in 16-foot rows on November 21, 1935. At a little distance away from these rod rows, wheat was drilled in at right angles to the previous sorghum rows. Both in this larger field and in the rod rows of wheat, near maturity, the locations of the previous milo rows were easily distinguished by the markedly reduced height of the plants. Some fertilizer trials within this adjoining field of wheat were made with nitrogenous fertilizers. Where these fertilizer plats crossed the previous milo rows, the decrease in height disappeared.

It has been observed by the writer that when sorghum plants at maturity are pulled up or plowed out there may be a considerable exudation of root sap from the end of the roots yet remaining in the soil. Each of these wet spots may attain 3 or 4 inches in diameter, undoubtedly at the expense of the sap within the roots of the plants distributed to considerable distances from the cut, i. e., upper, ends of the roots. Though no attempts to analyze this exudate have been made by the writer, this "bleeding" might cause a concentration of the sugars into the soil at or near the crowns of the previous crop. Another factor which might have been the cause of the greater injury from the milo was the heavier soil where the milo was grown as compared to that where the corn and sorgho were grown. Though no quantitative observations were made, it was felt that there was a greater amount of roots immediately at the bottom of the mulch where the Double Dwarf milo was grown than where the other two crops grew. It will be observed in Table 4 that the single rows of wheat immediately over the previous crop rows of Double Dwarf milo were reduced to almost one-half of the average of the adjacent rows. This decrease is highly significant statistically. With regard to yield of total crop the decrease of this one row is slightly greater than twice the decrease of the two rows for the Honey sorgho, but with regard to grain the decrease chargeable to milo injury is much greater than twice that chargeable to each of the two rows following the sorgho.

In Figs. 1 B and 1 C are given the distribution of yields of rod rows of wheat with respect to the previous crop rows for total crop and threshed grain, respectively. If these are compared with the concentration of sugars in p.p.m. of the dry soil as found for sorghos and shown immediately above in Fig. 1 A, it can be readily seen that the locations of the injury and of the peaks in the distribution of the sugars coincide.

## DISCUSSION

A complete case for the establishment of these sugars as a cause of the injury would need some evidence as to the amount of decrease in crop yields which a given amount of sugar would cause. Such a study has been made in a preliminary way in the field and in a more complete way in the greenhouse, but the subject is so complicated that it seems desirable to publish it later. Suffice it to say that as little as 100 p.p.m. of sucrose added to soil in pots has decreased the yield of non-leguminous crops about 10% during a 7 weeks' growing period.

It is realized that in the field many factors may cause variations from these results. The length of the growing period is longer, the sucrose undoubtedly is not distributed as equally as in pots, the soil temperatures in the field are different than they are in the greenhouse, and rains may leach either the sugars or the nitrates out of the root zone at the time when they might be most effective in causing decrease or increase to the indicator crop.

The sugars in the soil, if distributed as shown in Tables 2 and 3, would be expected to influence only the wheat rows planted over or adjacent to the previous crop rows as high concentrations do not extend more than 6 inches either way from the previous crop row, as shown in Fig. 1 B. Then practically all of the injury from the sugars of the roots would be operative on the one row of wheat immediately over the milo row and on the two rows immediately adjacent to the previous sorgo row.

When these experiments were planned it was hoped that there would be a general average of crop yields following sorgo and even corn which would be lower than on the adjoining fallow. It has been our usual experience that the cultural methods used for these studies would result in such data, but in this case either the soil chosen was so fertile or the rains so persistent and leaching as to remove this difference. However, the data reported previously (4) with regard to the vertical and horizontal distribution of nitrates and moisture at this same time and location are of interest. The rainfall, of course, was sufficient during the 1935-36 season to remove moisture as a factor limiting the wheat crop. The amount of nitrates in the soil at the end of the sorghum- and corn-growing period showed little relation to the variations in yield secured. The nitrates, however, are better correlated with the yields of crops across a sorghum-fallow and corn-fallow boundary line as usually encountered in the past.

Though not demonstrated in this study possibly because of conditions of the plats chosen or the season, the amount and distribution of residual nitrates, as previously reported (4), occurring on these plats at the same time as the samples for sugars were taken, are consistent with the idea that the sorghum crop by absorbing nitrates and possibly other available nutrients in the soil reduces the supply at the disposal of the succeeding crop, thereby reducing its yield. The analytical data would indicate that such an effect might be general over the area cropped to sorghums where a stand sufficiently thick was maintained. This coincides closely with the opinion of many agronomists that considering the higher yields of sorghums it is to be ex-

pected that these crops will make heavy drafts on the soil, leaving less for the succeeding crops.

But in addition to the idea of the heavy draft by the living sorghum plants, the data contained herein clearly indicate that the sugars contained in the roots of sorghums may be so concentrated in and near the crowns of the plants as to cause soil micro-organisms, acting to decompose them, to compete with the plants of the succeeding crop, giving results harmful to the latter. Injury from this cause seems to be confined to narrow zones, each extending along an old sorghum row and not very far distant from it. Such zones of injury coincide with zones of high sugars in the soil.

### SUMMARY

1. Samples taken with a soil tube from beneath corn and sorgo rows showed from 20 to over 200 times as much sugars as sucrose in the soil beneath the crowns of sorgo than under those of corn.

2. By taking larger soil samples with a spade in such a way as perhaps to be more representative of the condition sampled, than with the tube, the residual sugars expressed as sucrose were shown to occur both vertically and horizontally in highest concentrations near the crowns of the plants. Vertical slices to a depth of 1 foot, exceeding 100 p.p.m. of sugars, were not encountered over 6 inches from row centers while at the sorgo row center some were over 4,000 p.p.m. Horizontal 1-inch layers in the row and extending 4 inches on each side of it, ranged from over 12,000 p.p.m. of sugars in the first such layer to less than 10 p.p.m. in the 10th inch layer.

3. Rows of wheat parallel to the previous crop rows showed marked and statistically significant decreases adjacent to and over the row centers of sorgo and milo, while the slight decreases adjacent to previous corn rows were not significant.

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## BUNT REACTION OF SOME VARIETIES OF HARD RED WINTER WHEAT<sup>1</sup>

H. A. RODENHISER AND K. S. QUISENBERRY<sup>2</sup>

IN the fall of 1930 a coordinated cooperative improvement program for hard red winter wheat was started in the principal winter wheat producing states of the Great Plains. Because of the importance of covered smut or bunt in this area, a study of the reaction of wheats to the bunt organisms was included in the program in 1931 on a more extensive scale than studies then in progress at the state and federal experiment stations. Prior to this time many of the promising selections and hybrid lines were being tested for bunt reaction at a single station and with inoculum obtained from one locality or even from a single field. As a result, certain varieties found to be resistant in these tests were susceptible when grown commercially and subjected to other races of the bunt organism. It was apparent that, for an adequate test of varieties and promising strains, bunt reaction should be determined under a wide range of environmental conditions and by using collections of inoculum representative of various sections of the Great Plains. The purpose of this paper is to present results of bunt tests with uniform sets of winter wheat varieties and strains inoculated with the bunt organisms of a large number of collections and grown at a number of stations throughout the hard red winter wheat region.

### PLAN OF THE UNIFORM NURSERIES

Fifty varieties and strains of wheat were planted in duplicate 8-foot rows each year. Most of the wheats tested were new hybrid strains found to be resistant to bunt at the stations where they were developed, but, in addition, wheats grown in the uniform plat and nursery tests and a few varieties adapted primarily to the Northwest also were included. Kharkof (C. I. 1442), Cheyenne (C. I. 8885), and Quivira (C. I. 8886) were included in all tests as susceptible checks. Varieties were discontinued from the experiments as soon as it seemed that a satisfactory determination of their bunt reaction had been obtained, if they had developed an average of more than 10% bunt or proved to be undesirable agronomically.

Seed used in the tests in the first three years was treated with formaldehyde, thoroughly washed with water, and dried before applying the inoculum. In later years the seed was not treated but was taken from sources free from bunt infection.

The inoculum used for each of the nurseries was a composite of collections obtained not only in the vicinity of the station but also from fields selected at random throughout the state in which the test or

<sup>1</sup>Cooperative investigations of the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the agricultural experiment stations of Texas, Oklahoma, Kansas, Colorado, Nebraska, Minnesota, Montana, Utah, and West Virginia. Received for publication February 24, 1938.

<sup>2</sup>Pathologist and Agronomist, respectively. The writers express their appreciation to cooperators at the various experiment stations for their kindness in growing the nurseries.

tests were made. The most intensive bunt surveys in the Great Plains area have been made in Kansas and Montana, and the inoculum used in the nurseries at Manhattan, Kans., and Bozeman and Moccasin, Mont., included a larger number of collections than in tests conducted elsewhere. The inoculum used at Manhattan, Kans., was pure for the smooth-spored species (*Tilletia levis* Kühn). At all other stations a small percentage of *T. tritici* (Bjerk.) Wint. was present except in the Montana inoculum, where about 25% of the chlamydospores were of *T. tritici*. The definite physiologic races known to be present in the inoculum will be referred to in another section of this paper.

Nurseries were planted in some or all of the 6 years the tests have been made at Denton and Amarillo, Texas; Stillwater and Woodward, Okla.; Manhattan, Kans.; Akron and Fort Collins, Colo.; Lincoln, North Platte, and Alliance, Nebr.; St. Paul, Minn.; Moccasin and Bozeman, Mont.; Logan, Utah; and Kearneysville, W. Va.

The bunt percentages obtained were based on counts of the total number of bunted and non-bunted heads per row.

#### DATA OBTAINED

A summary of the data obtained at the different stations during a 6-year period is presented in Table 1. Data were not recorded from all stations every year because of environmental conditions unfavorable for bunt infection or for subsequent plant growth. The number of years individual varieties have been tested is not uniform owing to the rapid turnover in varieties. Consequently, the average percentage of infection is given in terms of percentage of Kharkof (C. I. 1442), which was grown every year at all stations, in order that the reaction of varieties may be compared directly. It is realized that this method of comparison is open to some criticism, but it gives usable and fairly comparable infection percentages. The varieties are listed in Table 1 in order of resistance as expressed in terms of the Kharkof check.

A total of 162 varieties and strains were tested for 1 to 6 years during the period from 1931 to 1937. No variety was entirely free from bunt in all tests, although 12 strains had average infections of less than 1% and 84 had less than 10%. It should be noted particularly that among the resistant varieties and selections are some that are grown commercially, including Redit, Minturki, Oro, and Yogo. These, together with the Nebraska Turkey selections (C. I. 10016 and C. I. 10094) and Hussar are being used as parents for the development of bunt-resistant strains. It is obvious from the data that most of the resistance in hybrid lines was obtained from crosses in which Oro, Martin, or Hussar were parents.

Attention should be called to the 14 strains of Oro × Tenmarq. Twelve of these produced less bunt than did Oro and all of them much less than Tenmarq. While all of these lines were selected for resistance, it seems possible, as pointed out by Wismer (4),<sup>3</sup> that Tenmarq may have contributed some genetic factor or factors for resistance to produce lines more resistant than the Oro parent.

<sup>3</sup>Figures in parenthesis refer to "Literature Cited", p. 492.

TABLE 1.—Summary of bunt infection of varieties and strains of winter wheat grown in the uniform winter wheat nursery in the Great Plains area, 1932-37.

Variety	C. I. No.	State No.	Percentage bunt infection in						"Dwarf" snut, Logan 1937, %	Weighted average* %	Per- centage of Kharkof
			1932, 8 sta- tions	1933, 6 sta- tions	1934, 10 sta- tions	1935, 9 sta- tions	1936, 9 sta- tions	1937, 10 sta- tions			
Oro X Tenmarq. . . . .	11675	Kans. sel. No. 342021	—	—	—	0.3	—	—	—	0.3	0.6
Martin X Blackhull X Blackhull. . . . .	11572	Hyb. No. 29312A-3-11	—	—	—	0.2	—	—	—	0.4	0.9
Beloglina X Hussar. . . . .	11583	North Platte No. 99	—	—	0.1	0.5	0.4	0.8	0.7	0.4	0.9
Turkey selection. . . . .	11507	Nebr. No. 4311	—	—	—	—	0.2	0.8	8.3	0.3	0.9
Turkey selection. . . . .	11095	Nebr. No. 1065	0.7	0.3	0.6	—	—	—	—	0.6	1.3
Turkey selection. . . . .	11577	Nebr. No. 1081	—	0.5	0.7	—	—	—	—	0.7	1.3
Beloglina X Hussar. . . . .	11810	North Platte No. 65..	—	—	—	—	—	0.7	6.3	0.7	1.5
Beloglina X Hussar. . . . .	10098	Nebr. No. 1070	1.1	0.5	0.6	—	—	—	—	0.7	1.6
Turkey selection. . . . .	11506	Nebr. No. 1067	0.5	0.3	1.2	—	—	—	—	0.7	1.6
"Tiflis". . . . .	11730	F. P. I. 94476	—	—	—	—	0.6	—	—	0.6	1.7
Martin X (Tenmarq)3. . . . .	11805	Denton No. 59-33-63	—	—	—	—	—	0.8	1.5	0.8	1.8
Turkey selection. . . . .	10097	Nebr. No. 1068	0.5	0.6	1.2	—	—	—	—	0.8	1.8
Kanred X Oro. . . . .	11803	Denton No. 18-33-32	—	—	—	—	—	1.0	3.2	1.0	2.2
Beloglina X Hussar. . . . .	11513	North Platte No. 126	—	—	0.2	1.1	0.3	3.3	7.0	1.1	2.5
Oro X Tenmarq. . . . .	11676	Kans. sel. No. 342039	—	0	—	1.3	—	—	—	1.3	2.5
Oro X Tenmarq. . . . .	11507	Kans. sel. No. 343638	—	—	—	—	—	1.3	72.4	1.3	2.8
Martin X Blackhull X Blackhull. . . . .	11571	Hyb. No. 29312A-2-12	—	—	0.7	2.6	—	—	—	1.6	3.0
Beloglina X Hussar. . . . .	11582	North Platte No. 80	—	—	0.7	2.6	—	—	—	1.6	3.0
Wheat X Rye (Meister). . . . .	11493	—	—	—	—	1.8	2.7	0	3.4	1.4	3.1
Beloglina X Hussar. . . . .	11514	Nebr. No. 1069	0.8	0.9	1.7	—	—	—	—	1.4	3.1
Turkey selection. . . . .	10016	Nebr. No. 1069	0.8	0.5	0.9	1.5	2.8	2.0	80.5	1.5	3.3
Relief. . . . .	10082	—	—	—	—	—	1.6	1.6	—	1.4	3.3
Martin X (Tenmarq)3. . . . .	11804	Denton No. 59-33-23	—	—	—	—	—	1.6	—	1.4	3.4
Oro X Tenmarq. . . . .	11677	Kans. sel. No. 342048	—	—	—	—	—	1.6	2.6	1.4	3.4
Oro X Tenmarq. . . . .	11720	Kans. sel. No. 343255	—	—	—	0.3	1.3	3.2	59.4	1.7	3.5
Tenmarq X Minturki. . . . .	11810	Kans. sel. No. 344231	—	—	—	—	0.6	2.7	54.4	1.7	4.1
Sibley No. 81. . . . .	10084	—	1.4	1.6	2.8	—	—	2.0	54.5	2.0	4.4
Turkey selection. . . . .	11576	Nebr. No. 1082	—	—	—	—	—	—	—	2.0	4.4
Turkey X Bd. Minn. No. 48. . . . .	8243	—	2.4	3.5	1.0	0.9	0.5	6.1	73.8	2.1	4.5
Turkey selection. . . . .	10094	Nebr. No. 1063	1.9	0.6	1.5	2.9	2.1	3.0	57.6	2.1	4.7
Ridit X Nebr. No. 6. . . . .	11670	Nebr. No. 1097	—	—	—	5	1.1	4.7	61.0	2.2	4.9
Minturki X Blackhull. . . . .	11671	Nebr. No. 1089	—	—	—	1.4	1.6	3.5	61.9	2.2	4.9
Minturki X (Beloglina-Buffum). . . . .	10088	Hyb. No. 19115-VI-14	2.1	1.6	2.9	2.3	2.3	4.8	35.5	2.3	5.1
Yogo. . . . .	8033	—	1.7	1.0	1.1	—	—	—	—	2.3	5.1
Cooperatora. . . . .	8861	—	2.9	1.1	—	—	—	—	—	2.1	5.2
Cheyenne selection. . . . .	11666	Nebr. No. 1087	—	2.2	1.5	1.3	0.5	5.2	54.5	2.1	5.3
Turkey selection. . . . .	11376	—	—	—	—	2.6	3.4	—	—	2.4	5.4









Hope (C. I. 8178), which has been used with some success as a parent in crosses for the development of smut-resistant lines of spring wheat, appears in the present tests to be of little value for this purpose in winter wheat crosses. Although known to be resistant when planted in the spring it is susceptible when fall planted. For example, in the fall of 1936 at Arlington Farm, Arlington, Va., seed of Hope was tested with each of the races recently numbered by Rodenhiser and Holton (3). The variety was found to be resistant to only four of the 11 races of *T. tritici* and to none of the eight races of *T. levis*. Several of these races of *T. levis* are present in the Great Plains area and very probably account for the susceptible reaction of the Hope  $\times$  Mediterranean and Hope  $\times$  Kawvale crosses. It should be noted, however, that the H-44 (C. I. 8177), sister selection of Hope, when crossed with Minhardi (C. I. 5149), was resistant when tested at all stations in 1936.

Nurseries were planted in 1935 and 1936 at Logan, Utah, in cooperation with the Utah Agricultural Experiment Station, in order to determine the reaction of some of the hard red winter wheats to the so-called "dwarf" bunt organism, a race of *Tilletia tritici* prevalent in the Cache Valley. This bunt is known to be present also in Washington and Idaho, (2), and since it was first reported by Young (5), the writers have found it increasingly prevalent in the Gallatin Valley of Montana. The data obtained on the reaction to this organism are presented because of the possibility of its spread farther south and becoming a problem in the Great Plains area. The percentages of infection recorded in Table 1 are not, however, included in the averages obtained at the other stations. Ten of the 50 wheats tested showed less than 10% infection from this particular race of the "dwarf" bunt organism. The hybrid strains showing resistance apparently derived this resistance from their parents, Martin (C. I. 4463), Hussar (C. I. 4843), or Kanred (C. I. 5146). Oro, which possesses factors for resistance to a great many collections of *Tilletia* in the Great Plains tests, has no resistance to this race. Likewise, there is no resistance in all crosses in which Oro is one of the parents. The resistance of Ioturk (C. I. 11388) should be noted, as well as that of Relief (C. I. 10082), which was the only variety entirely free from the "dwarf" smut. Because of its resistance to this race, Relief is now being grown rather extensively in the Cache Valley of Utah. Unfortunately, it is susceptible to other races of *Tilletia* that are known to occur in this area and in the Northwest.

The present tests have been made at a number of stations under a wide range of environmental conditions and with bulk inoculum of a number of collections of *Tilletia*. Under these conditions, susceptible lines have been readily determined and rapidly weeded out. There is some doubt, however, regarding the reliability of results where varieties have been recorded as resistant. Since the inoculum consisted of a number of collections, relatively few chlamydospores of a particularly virulent race may have been present and as a result of this dilution the virulence of any one race would be masked. Oro, Hussar, and Minturki which were used in some of the crosses as bunt-resistant parents, together with some of the Turkey selections, therefore were

inoculated separately with individual races known to be present in the hard red winter wheat area and in the bulk inoculum.<sup>4</sup> In these tests, Oro, Hussar, the Turkey selections (C. I. 10016 and 10094), and Cheyenne selection (C. I. 11666) were all resistant to the individual races that have so far been identified in the hard red winter wheat area exclusive of Montana. Minturki was intermediate in its reaction to race L-3, which is known to be present in Kansas. The resistance of these wheats to all of the races found in Montana was not maintained. With the exception of Hussar they were highly susceptible to one race, L-8, and Hussar was intermediate in its reaction to L-6 and susceptible to T-8.

It is obvious from these data that bunt-resistant reactions obtained as a result of tests in which bulk inoculum is used should be considered in the nature of preliminary evidence and that such tests should be supplemented with others using at least the individual races present in the area to which the wheat is adapted and preferably all of the known races. Failure to do this may result in a repetition of the experience encountered with Yogo (C. I. 8033). In the uniform bunt nursery tests this variety was repeatedly classed as a resistant variety and as such was released for commercial production in 1935. That year Yogo, among other varieties, was inoculated with individual races and as a result was found to be highly susceptible to race L-8 now known to be generally distributed in Montana and the Northwest.

It is not within the scope of this paper to discuss further the importance of races of the bunt organism with relation to the wheat-breeding program. Pertinent data have been presented, however, in recent papers by Aamodt (1) and by Rodenhiser and Holton (3).

#### SUMMARY

Bunt nurseries of hard red winter wheat were grown for 1 to 6 years at 10 experiment stations in the Great Plains states and at Kearneysville, W. Va., St. Paul, Minn., and Logan, Utah. Each nursery contained 50 varieties and strains of winter wheat grown in duplicate rows. The inoculum used was a composite of collections of *T. levis* and *T. tritici* obtained from fields selected at random throughout the state in which the test or tests were made.

No variety or selection proved to be bunt-free at all stations, but a large number may be classed as resistant. Oro, Martin, and Hussar, and Minturki to a limited extent, contributed factors for resistance, in hybrid lines, to the races of the bunt organism used in these tests except those collected in Montana. The four above-mentioned varieties were susceptible when inoculated individually with certain races present in Montana and other wheat-growing areas.

Bunt-resistant reactions determined by experiments in which bulk inoculum is used should be considered as preliminary evidence only, and such tests should be supplemented by others in which the known races of *Tilletia* are used individually.

<sup>4</sup>This test was made at Pullman, Wash., and Bozeman, Mont., in cooperation with Dr. C. S. Holton.

Only 10 of 50 wheats tested proved to be resistant to the so-called "dwarf" smut race of *T. tritici* prevalent in the vicinity of Logan, Utah, and in the Gallatin Valley of Montana. Factors for resistance to this race are present in Martin, Hussar, Ioturk, and Relief.

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## INFILTRATION CAPACITY OF SOME ILLINOIS SOILS<sup>1</sup>

R. S. STAUFFER<sup>2</sup>

SOILS men have long recognized the necessity of defining observable features which may be used in differentiating soils. There is a growing appreciation among them of the need for the establishment of further physical and chemical criteria which cannot be observed in the field. The agronomists are now calling for information of this type, since the cropping behavior of a soil is frequently dependent on its physical and chemical properties, which can be determined only in the laboratory or in the field by laboratory methods.

The work reported in this paper has to do with one phase of moisture movement in soils, namely, infiltration capacity. The need for this type of information has become particularly pressing in recent years in connection with the widespread soil and water conservation efforts of the experiment stations and of the Soil Conservation Service.

The results reported in this paper are in the nature of a progress report, as there are many problems of technic and interpretation which remain to be worked out as the investigation progresses.

### METHODS AND PROCEDURE

Tests were made at 14 locations scattered over the state of Illinois on soils which differ widely in infiltration capacities. These will be referred to by numbers 1 to 14, inclusive. With the exceptions of numbers 4, 5, and 6, the determinations were made on soils with a grass cover which had not been plowed for many years. Soils numbered 4, 5, and 6 occur on areas which had been seeded to grass the previous year.

The apparatus used and procedure followed in the investigation were similar to those reported by Musgrave,<sup>3</sup> with certain exceptions that will be noted. When the exact location for a test was selected the vegetation was removed by cutting it off with a sharp knife just flush with the surface of the soil. Cylinders 8 inches in diameter and long enough to reach into the B horizon were forced vertically into the soil to the desired depth by means of a hydraulic jack. A loaded truck was used to supply the necessary weight (Fig. 1). Perforated brass disks, which fit snugly inside the cylinders, were placed on the surface of the soil. A tent, large enough to cover all the cylinders, was set up so the determination could proceed in case of rain. The burettes, described below, were then placed in position (Fig. 2), filled with water, and measurements were started. Readings were taken at 5-minute intervals for 30 minutes, at 10-minute intervals for 1 hour, at 15-minute intervals for 1 hour, and at 30-minute intervals for 1½ hours. Thereafter hourly readings were taken till the whole period covered 24 hours or more with two exceptions which were continued for 22 hours.

Before the cylinders were forced into the soil they were covered both inside and outside with a thin coat of ordinary cup grease. This caused the cylinders to

<sup>1</sup>Contribution from the Division of Soil Physics, Department of Agronomy, University of Illinois, Urbana, Ill. Published with the approval of the Director of the Experiment Station. Received for publication February 24, 1938.

<sup>2</sup>Associate in Soil Physics.

<sup>3</sup>MUSGRAVE, G. W. The infiltration capacity of soils in relation to the control of surface runoff and erosion. Jour. Amer. Soc. Agron., 27:331-336. 1935.

penetrate the soil more easily and also lessened the likelihood of water passing down between the core of soil and the cylinder. In addition it was found that the soil column was not so likely to be depressed in the cylinder. In fact the reason



FIG. 1.—Equipment for forcing cylinders into the soil

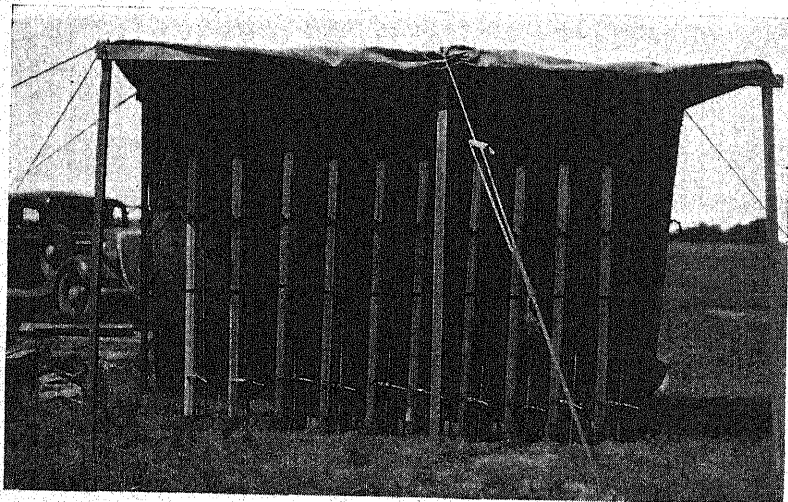


FIG. 2.—Cylinders, burettes, and part of tent in position.

grease was used on the cylinders was because the first soil on which measurements were attempted compressed very badly as the cylinder was forced downward into the soil. After applying the grease this did not occur, and since the grease did not penetrate the soil mass, it was decided to use it regularly.

The burettes, which have a capacity of 3,600 cc, were made of galvanized iron down-spouting. The down spouting was cut into desired lengths, the seams soldered tightly, and short copper tubes for inlets and outlets were soldered on the ends. A glass tube for making the readings was graduated at 10-cc intervals and was connected to the spouting near the ends.

The amount of evaporation was determined by putting a measured amount of water at the beginning of a test into a container of the same diameter as the cylinders. The surface of the water in this container was about the same distance from the top of the container as the water in the cylinders was from the tops of the cylinders. At the end of a test the water in the container was measured again. The difference was the amount of water evaporated.

Since the viscosity of water is affected by changes in temperature, it seemed desirable to get some idea of the temperature variation. The temperatures of the water in the cylinders and of the soil at a depth of 3 inches were recorded several times during the day and night while a determination was in progress.

At the time of a determination, samples of soil were taken near the cylinders for moisture determinations. Since the percentage of water in a soil does not convey much meaning unless additional information is available, the "relative wetness" as described by Conrad and Veihmeyer<sup>4</sup> is used. It is the percentage of water in the soil divided by the moisture equivalent times 100.

#### DESCRIPTION OF THE SOILS

Soils numbered 1, 2, and 3 occur in the brown-gray area<sup>5</sup> of southwestern Illinois. Soil number 1 is characterized as brown-gray silt loam on tight clay. It was formed from loess or loess-like material and occurs on level or nearly level topography. The surface soil is a dark grayish-brown silt loam, with small, granular, well-developed but easily broken down, structure particles. The B horizon, which is very plastic, possesses fairly well-developed prismatic structure. Glacial till could not be definitely identified until a depth of 95 inches had been reached. No calcareous material was encountered to a depth of 125 inches.

Soils numbered 2 and 3 are slick spots which are characteristic of this area of Illinois and which make up a considerable percentage of the area. They have a shallow, gray surface soil and possess very slight structure development anywhere in the profile. Number 2 was calcareous at 17 inches and this continued down to a depth of 45 inches, below which it was not calcareous. Soil number 3 is similar to number 2 except it had reached a more advanced stage of slick spot development. It was calcareous at a depth of 13 inches.

Soils numbered 4, 5, 6, and 7 occur in the southern part of Illinois south of the glaciated area. They have apparently been developed from loess deposited on residual material. The depth to bed-rock, a red, fine-grained sandstone, ranged from 90 inches in number 6 to 122 inches in number 7. Numbers 4 and 5 occur on an 8% slope. The test was made on number 5 about 10 rods from the top of the slope and on number 4 about 10 rods further down the slope. Soil number 6 occurs on a 5% slope and number 7 on a nearly level area on the top of a hill about 6 rods from the nearest break in the relief. Soils numbered 4, 5, and 6 are very similar. The surface soils are shallow, grayish yellow, silt loams. While these soils are not highly plastic they are very compact throughout the profile. Soil number 7

<sup>4</sup>CONRAD, JOHN P., and VEIHMAYER, F. J. Root development and soil moisture. *Hilgardia*, 4:4. 1929.

<sup>5</sup>SMITH, R. S., *et al.* Parent materials, subsoil permeability, and surface character of Illinois soils. Univ. Ill. Agr. Exp. Sta. 1935.

differs from the other three chiefly in that it has a deeper and darker colored surface soil, due probably to the fact that it has been less eroded.

Soil number 8 is a grayish dark brown, heavy silt loam or clay loam on clay and is characteristic of the grayish brown area of west central Illinois.<sup>6</sup> It occurs chiefly where the topography is nearly level. The surface soil is deep and possesses a well-developed, finely granular, structure. The parent material of this soil is loess, which at this location is about 100 inches deep. Soil number 9 is similar to number 8 except that it occurs on slightly higher ground. The surface soil is lighter in color and apparently less plastic than that of number 8, but the B horizon seems to be more plastic.

The descriptive name of soil number 10 is brown silt loam. It was formed from loess and occurs on undulating topography. The surface soil is brown in color and possesses a granular condition. The B horizon is slightly plastic, but water passes through it readily. No glacial till was encountered to a depth of 120 inches where this determination was made. Carbonates were found at a depth of 45 inches. This soil is typical of the soils that occur in the deep loess area of northwestern Illinois.

Soil number 11 is similar to number 10 except that it occurs on more rolling topography, and the surface soil is lighter brown in color. The B horizon shows only slight accumulation of fine material and permits water to pass through readily. No carbonates were found to a depth of 70 inches and at the location where this determination was made the loess was more than 100 inches in depth.

Soil number 12 is described as brown silt loam on compact, medium plastic, calcareous till. It occurs where the topography is undulating to gently rolling. The surface soil is dark brown clayey silt loam or clay loam, and is well granulated. The B horizon is plastic and like the underlying till seems to be relatively impervious to water.

The descriptive name of soil number 13 is gray silt loam on tight clay. It occurs on the flat prairie areas of Illinois on what is known as the Lower Illinoian Glaciation. Water does not penetrate this soil readily because of the tight B horizon and also because of the underlying Illinoian gumbotil.

Soil number 14 is described as brown silt loam on till. It occurs on the older parts of the Wisconsin drift area where the topography is rolling. The A horizon is brown silt loam. The B horizon, which apparently was developed from drift, is only slightly plastic. The whole profile is readily permeable to water.

## RESULTS AND DISCUSSION

The infiltration capacities of the soils included in this study are given in the form of graphs in Fig. 3, which covers a 2-hour period, and in Fig. 4, which covers a 24-hour period. Each graph represents the average of a number of individual determinations, ranging from 5 to 10. Since this is probably too small a number to be treated statistically the extremes and averages of all individual determinations in each setup are given in Table 1, for 1, 2, and 24 hours. The amount of water in surface inches evaporated during the 24-hour period of each setup is also given in Table 1.

In both Figs. 3 and 4, the graphs for soils 10, 11, and 14 run off the paper. This seemed less undesirable than to use a smaller scale which would throw the graphs of the other soils too closely together to be distinguished. Furthermore, so far as the graphs in Fig. 4 are concerned, it is doubtful whether the results after 10 or 12 inches of

<sup>6</sup>See footnote 5.



water were absorbed are of any significance because that amount of water would ordinarily be sufficient to saturate the soil column to the bottom of the cylinders. Any additional water could not be considered as the amount of water a given area of soil would absorb because of the horizontal spreading of the water below the cylinder. The total average infiltration capacities of soils 10, 11, and 14 for 1, 2, and 24 hours can be seen in Table 1.

TABLE 1.—*Minimum, maximum, and average infiltration in surface inches of all determinations made on each soil and evaporation during the determination.*

Soil No.	1 hour			2 hours			24 hours			Evaporation, surface inches
	Min-imum	Max-imum	Aver-age	Min-imum	Max-imum	Aver-age	Min-imum	Max-imum	Aver-age	
1	0.63	0.88	0.78	1.09	1.31	1.22	3.17	9.87	6.22	0.12
2	0.27	0.47	0.37	0.41	0.64	0.54	0.95*	1.20	1.10	0.11
3	0.03	0.34	0.15	0.04	0.39	0.18	0.34*	0.58	0.47	0.11
4	0.15	0.78	0.60	0.37	1.33	1.06	1.41	2.46	2.07	0.10
5	0.38	1.25	0.73	0.72	1.33	1.06	1.46	2.29	1.88	0.10
6	0.19	0.81	0.45	0.27	1.05	0.67	1.48	1.89	1.62	0.08
7	0.19	0.59	0.34	0.36	0.90	0.56	2.13	2.69	2.36	0.07
8	0.77	1.19	0.96	1.18	1.60	1.36	2.29	6.22	3.91	0.14
9	0.25	0.62	0.41	0.40	0.89	0.56	1.18	3.98	2.16	0.14
10	3.35	7.75	5.36	5.87	12.09	9.00	35.66	65.58	48.10	0.11
11	3.96	10.58	5.91	6.52	19.61	10.58	40.33	69.85	58.57	0.10
12	0.11	0.99	0.71	0.13	1.07	0.78	0.74	2.55	1.45	0.12
13	0.03	0.67	0.34	0.16	0.80	0.43	0.56	1.57	0.98	0.06
14	2.00	5.30	3.70	3.24	10.74	6.68	23.37	52.43	35.96	0.12

\*For 22 hours.

Since it was not clear how to make proper corrections for variation in the viscosity of the water due to temperature differences, such corrections are not attempted. The widest range in temperature of the water for a 24-hour period was 7° C and for that of the soil at a depth of 3 inches, 3°. The extreme range of temperatures during the whole series of determinations was 15° for the water and 14° for the soil. At Urbana, Ill., during this same period, the soil temperatures at a depth of 24 inches varied 6° C and at a depth of 8 inches, 13°. The temperature ranges for these depths are given because 24 inches is deep enough to reach into the B horizon of most soils, probably the least permeable portion of the profile, and 8 inches is as deep as the added water penetrated several of the soils included in this study.

The amount of water already in a soil when a test is being made will influence the results on infiltration capacity. The results of the moisture determinations made in this study are given in Table 2. They show that the moisture contents of most of the soils were relatively high.

No correction is made for the loss of water by evaporation because the evaporation was measured for the whole period of a determination and not for specific periods during the determination. Therefore, it is not known just how much to deduct from the total amount of water measured at any particular time interval. The amount of evaporation was insignificant in many cases, but when the infiltration capacity of a

soil is as low as that of number 3 the amount of water evaporated in 24 hours made up about 23% of the total amount of water measured by the burettes.

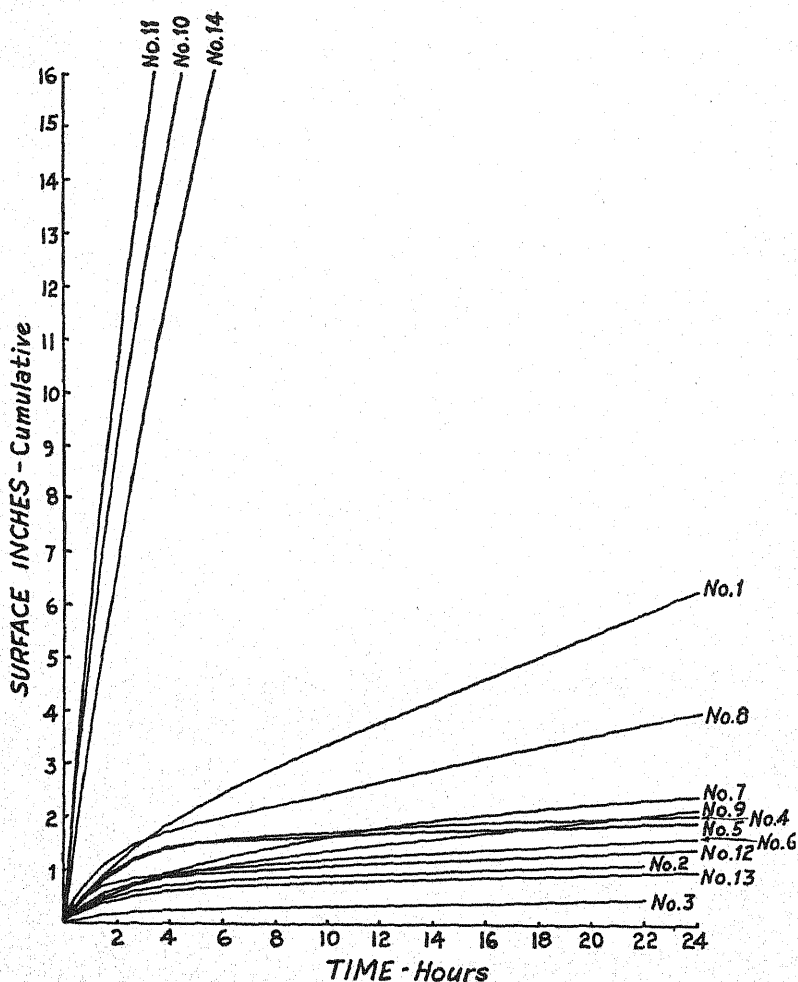


FIG. 3.—Infiltration capacity in surface inches of some Illinois soils for a 2-hour period.

Another factor that would be responsible for considerable variation in the infiltration capacity of the same soil type is the condition of the surface soil. As stated previously, the soils included in the study reported in this paper were under grass cover and in all but numbers 4, 5, and 6 had not been plowed for many years. If determinations were repeated on the same soil types but which had a different surface condition, due perhaps to being farmed, the results would un-

doubtedly differ from those reported here. This would be particularly true at the beginning of a run. For this reason care must be exercised in using such results in connection with erosion control measures,

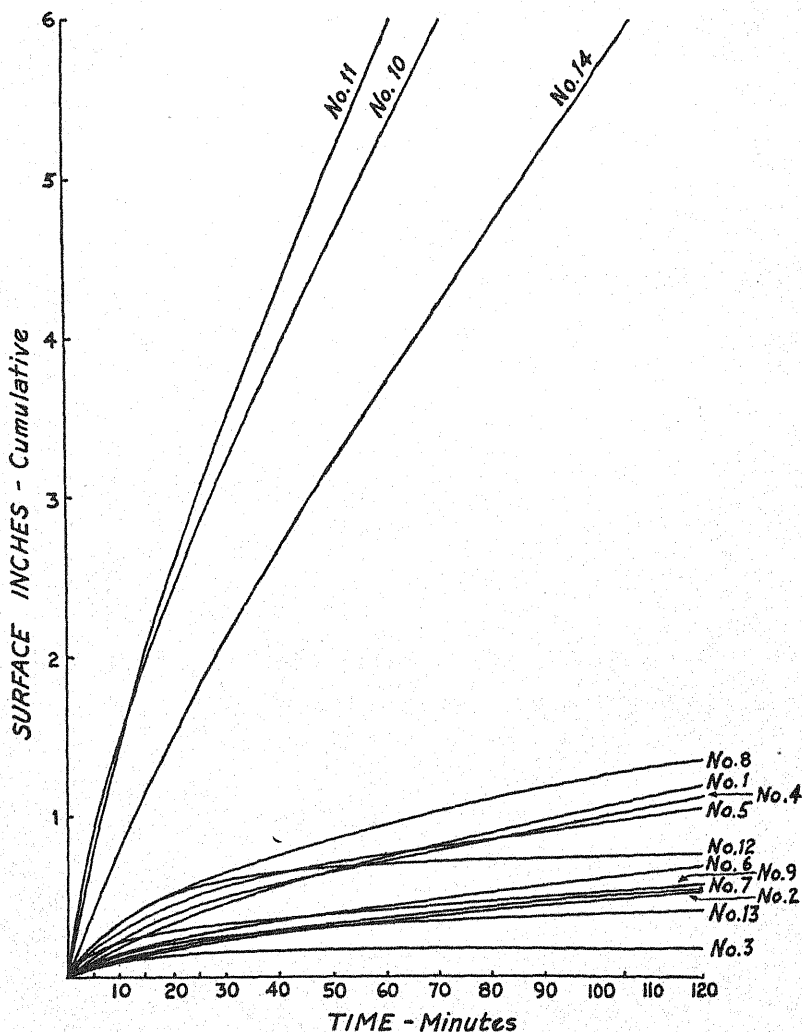


FIG. 4.—Infiltration capacity of some Illinois soils for a 24-hour period.

unless, as stated by Musgrave,<sup>7</sup> the results of such measurements giving the minimum capacity of the soil in question be used.

By the method employed in this study a head of water from 5 to 7 mm in thickness was maintained on the surface of the soil. Under such conditions the penetration of water might be interfered with because

<sup>7</sup>Loc. cit.

the air confined in the soil could not escape readily. However, it is doubtful if the conditions under which these tests were conducted are less favorable for the escape of confined air than those which obtain during the most intense rains. This would be particularly true for soils that are slowly permeable.

TABLE 2.—*Field moisture content, moisture equivalent, and relative wetness of some Illinois soils.*

Soil No.	Moisture content*			Moisture equivalent			Relative wetness		
	A <sub>1</sub>	A <sub>2</sub>	B	A <sub>1</sub>	A <sub>2</sub>	B	A <sub>1</sub>	A <sub>2</sub>	B
1	22.8	23.2	24.2	23.1	26.1	27.6	98.7	88.9	87.7
2	16.4	21.6	27.1	24.3	—†	—†	67.5	—†	—†
3	17.7	16.3	21.2	19.5	—†	—†	90.8	—†	—†
4	21.4	26.6	27.5	22.0	26.6	28.3	97.3	100.0	97.2
5	17.3	24.1	27.1	18.7	25.6	27.5	97.9	94.1	98.5
6	23.8	23.8	25.9	22.2	24.7	28.0	107.2	96.4	92.5
7	17.2	20.0	24.2	21.9	21.8	29.5	78.5	91.8	82.0
8	24.2	28.0	33.2	26.4	28.4	35.6	91.7	98.6	93.3
9	24.7	24.7	29.3	25.5	26.5	30.3	96.9	93.2	96.7
10	24.0	24.8	24.0	27.9	29.3	29.1	86.0	84.6	82.5
11	29.0	31.1	29.1	27.9	30.3	29.1	103.9	102.6	100.0
12	30.2	25.6	28.2	34.4	28.8	30.7	87.8	88.9	91.9
13	25.2	22.2	23.9	24.8	22.4	26.9	101.2	99.1	88.8
14	22.2	24.8	25.2	23.8	23.6	24.9	93.3	105.1	101.2

\*Percentage by weight, oven-dry basis.

†Could not determine moisture equivalent because water would not pass through soil, therefore, could not determine relative wetness.

It is interesting to note the graphs for soils numbered 4 and 5, particularly in Fig. 4. These graphs are the same shape and remain close together during the whole 24 hours of the determination. As mentioned previously, these two setups were made on the same slope. Soil number 5 was 10 rods farther up the slope than soil number 4.

#### SUMMARY AND CONCLUSIONS

1. The infiltration capacities of several Illinois soils were determined at 14 locations.
2. The results indicate that at three of these locations the soils have high infiltration capacities and at 11 of the locations they have low infiltration capacities.
3. There are a number of factors which may cause the infiltration capacities of soils to vary, but the dominant factor seems to be the physical character and condition of the soils themselves.
4. The main purpose of this project is to secure information that will be of value in characterizing soils and in soil and water conservation. However, to characterize a soil on this basis more determinations than have been made are necessary. Furthermore, it seems that these determinations should be made at locations selected to give the range covered by the soil type in question, rather than at locations where the soil is considered "typical," as is frequently done.

## SEED SETTING AND AVERAGE SEED WEIGHT AS AFFECTED BY TWO METHODS OF OPENING BARLEY FLOWERS FOR EMASCULATION<sup>1</sup>

O. T. BONNETT<sup>2</sup>

EMASCULATION and cross-pollination of barley is a tedious and time-consuming process and any method that will bring about an increase in the percentage of seed set and an increase in the average weight a seed is of value. If, in cross-pollination, a high percentage of the flowers set seed, the number of flowers that must be crossed to obtain a given number of seeds can be reduced and thus bring about a saving in time and effort. Furthermore, crossed seed as near the same size as the naturally produced parent seed is also desirable when the growth of the  $F_1$  plants is to be compared with that of their parents.

Tschermac (4)<sup>3</sup> has described the technic of crossing wheat, oats, rye, and barley. He opened barley flowers for emasculation and artificial cross-pollination by cutting off the upper one-third to one-half of the tips of the lemmas and paleas. Pope (2) described a rapid method for making small grain hybrids. His method was concerned with the manner of applying pollen to the emasculated barley flowers and not with the method of opening the barley flowers for emasculation. Woodworth and Bonnett (5) published a photograph showing the two methods of opening barley flowers that are more fully discussed in the present article.

In the present paper a description will be given of two methods of opening barley flowers for emasculation and cross-pollination and data showing the effect of the two methods upon seed setting and seed size will also be presented. In addition, data will be given showing the effect of mutilating barley flowers in different ways upon the average seed weight.

### METHODS OF EMASCULATION

Barley heads were prepared for emasculation in the usual way. In Fig. 1 the various manipulations in preparing a barley head for emasculation are shown. When the awns extend 3 to 4 centimeters above the last blade (Fig. 1, A), the head is removed from the boot (Fig. 1, B and C). The base and tip spikelets are cut off with sharp-pointed scissors, leaving a number of spikelets in the middle of the head, and the side spikelets are also pulled or cut off (Fig. 1, D). The barley head is now ready for emasculation (Fig. 1, E).

Two methods of opening barley flowers were used. Both methods are shown in Fig. 1, F, and in Fig. 1, G, the latter figure being an en-

<sup>1</sup>Contribution from the Division of Plant Breeding, Department of Agronomy, University of Illinois, Urbana, Ill. Published with the approval of the Director of the Experiment Station. Received for publication February 24, 1938.

<sup>2</sup>Assistant Chief in Plant Genetics.

<sup>3</sup>Figures in parenthesis refer to "Literature Cited", p. 506.

largement of a portion of the head in Fig. 1, F. The flowers on the left side of the head have had the awns and tips of the lemmas and paleas cut off just above the anthers. The anthers were then removed

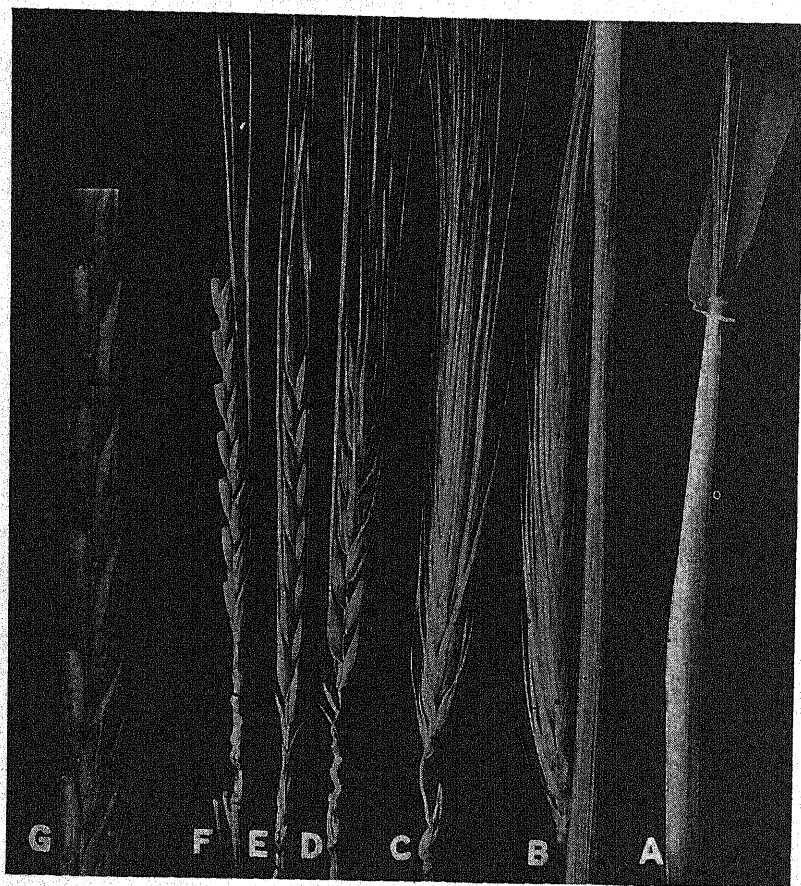


FIG. 1.—Various steps in the preparation of a head of six-row barley for emasculation. A, Appearance of a head of barley at about the proper stage of development for emasculation; B, the head, partly removed from the boot; C, the head, free of the boot; D, part of the basal, tip, and side spikelets removed; E, the spike, ready for emasculation; F, on the left side of the spike, the awn and tip of the flowering glumes removed; on the right side of the spike, awns normal lemmas slit; G, enlargement of a portion of F.

through the opening at the top of the flowers by means of small-pointed tweezers. On the right side of the spike the flowers have been opened by slitting the lemma with one point of the tweezers which had been sharpened for this purpose. Through the slit made in the lemma the anthers were removed and pollinations were made.

## EXPERIMENTAL RESULTS

A comparison was made of the effect of the two methods of opening barley flowers upon the percentage of flowers setting seed and upon the average weight of a seed. Wisconsin Pedigree No. 5, a six-row barley, was used as the pistillate parent and Spartan, a two-row barley, was used as the pollen parent. The plants were grown in pots in the greenhouse and at the proper stage for emasculation the heads of Wisconsin Pedigree No. 5 were prepared and the flowers opened as shown in Fig. 1, F, i. e., the lemmas and paleas of the flowers on one side of the head were cut off and the lemmas of the flowers on the other side of the head were slit. Two to three days after the flowers were emasculated both sides of the head were pollinated.

Differences were found in the percentage of flowers setting seed and in the average weight of the seeds. Of 61 flowers prepared for emasculation and cross-pollination by cutting off the glumes, 39, or 63.9%, of the flowers set seed which weighed, on the average, 38.8 milligrams a seed. Of 62 flowers opened for emasculation and cross-pollination by slitting the lemmas, 53, or 85%, of the flowers set seed which weighed, on the average, 43.5 milligrams a seed. There was an increase of 35.9% in the number of flowers setting seed and an increase of 12.1% in the average weight a seed in favor of the method of opening the flowers by slitting the lemmas.

Differences in seed size and seed setting are shown in Fig. 2. On the left the tips of the lemmas and paleas were cut off and on the right the lemmas were slit. The apparent differences in seed setting and seed size are greater than are indicated in the data given above. This is because the heads of barley shown in the illustration were grown at a different time than the heads from which the data on seed setting and seed size were taken. However, the illustration shows quite clearly the two methods of opening flowers.

Another experiment was conducted to determine the effect of methods of mutilating barley flowers upon the average weight of the seed. Spartan was grown in the field, and at the proper stage for emasculation the flowers were mutilated and allowed to self-fertilize. The flowers were mutilated in the following ways: (a) Awns cut off at the tip of the lemma, (b) glumes cut off to various lengths, and (c) the glumes slit. One-half of a head was mutilated in one way and the other half of the head in a different way. By mutilating each half of a head differently a better comparison could be made between the methods.

In Table 1 is given: (a) a comparison between certain methods of mutilation in their effects upon the average seed weight, and (b) a summary of the results.

Essentially the same conclusions are reached from a study of the summary as are obtained from a study of the paired methods of mutilation. Compared to the unmutilated flowers, slitting the lemmas produced the least reduction in average seed weight. Removing the awns brought about a slightly greater reduction in average seed weight than slitting the glumes. Cutting off the lemmas or paleas to a length of 7 to 8 mm caused a greater reduction in average seed weight than slitting the glumes, and cutting the lemmas and paleas to a length of 4 to 5 mm caused the greatest reduction in average seed weight.



Except where the lemmas and paleas were cut off to a length of 4 to 5 mm different methods of mutilation did not appear to make any real difference in the average number of seed set. When the lemmas

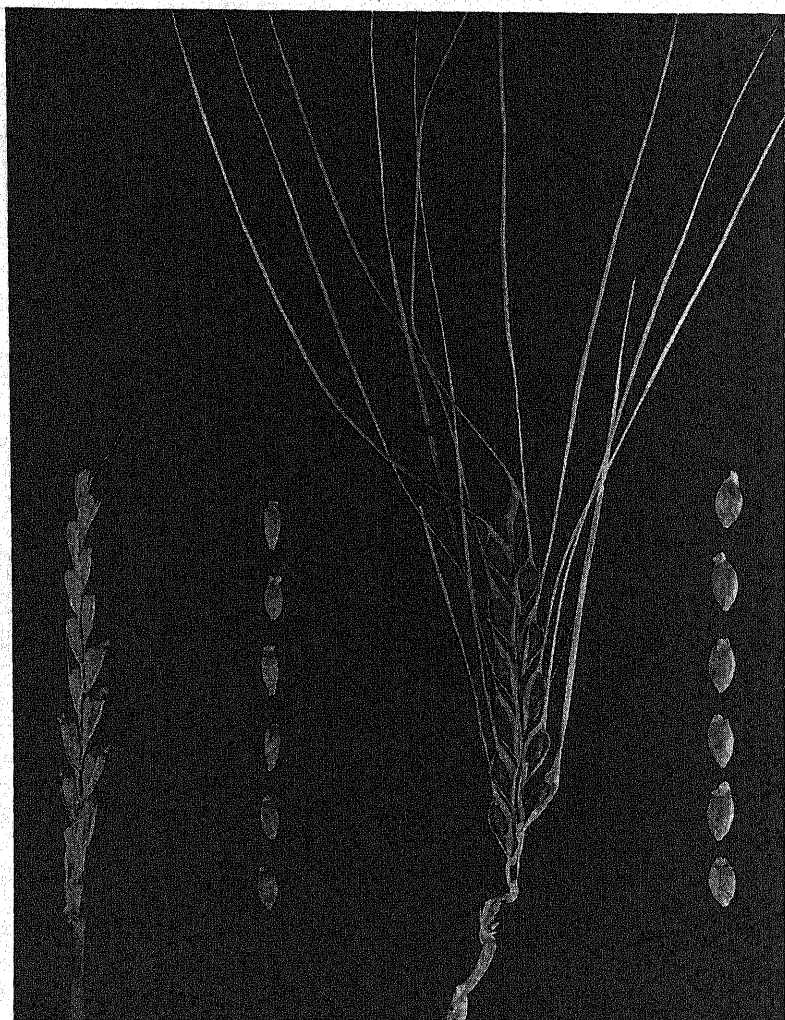


FIG. 2.—Showing the effect of two methods of opening barley flowers for emasculating upon the size of seed. Left, flowering glumes cut off; right, lemmas slit.

and paleas were clipped to 4 to 5 mm the tips of some of the anthers were also cut off, which probably interfered with the production of viable pollen and therefore reduced the percentage of flowers setting seed.



TABLE 1.—Average weight of barley seed as affected by mutilating barley flowers in different ways and permitting them to self-fertilize, each half of a head having been mutilated in a different way.

Kind of mutilation given respective halves	Total half heads	Total seeds	Average seed a half head	Average seed weight, mg	Difference	Difference as per cent of lower value
Awns left on, flowering glumes normal.....	2	18	9.0	53.05		
Awns left on, flowering glumes slit	2	17	8.5	44.70	8.35	18.68
Awns left on, flowering glumes normal.....	4	34	8.5	48.23		
Awns removed, flowering glumes normal.....	4	38	9.5	42.10	6.13	14.56
Awns removed, flowering glumes normal.....	4	37	9.2	39.59		
Awns removed, flowering glumes normal.....	4	35	8.7	39.42	.17	.04
Awns left on, flowering glumes slit	9	82	9.1	40.54		
Awns removed, flowering glumes clipped to 7-8 mm*.....	9	85	9.5	32.82	7.72	23.52
Awns left on, flowering glumes normal.....	7	58	8.2	48.44		
Awns removed, flowering glumes clipped to 4-5 mm.....	7	46	6.5	19.13	29.31	153.21
Awns left on, flowering glumes slit	10	86	8.6	42.09		
Awns removed, flowering glumes clipped to 4-5 mm.....	10	71	7.1	21.97	20.12	91.57
Summary						
Awns left on, flowering glumes normal.....	13	110	8.4	49.13		
Awns left on, flowering glumes slit	21	185	8.8	41.65	7.48†	17.95
Awns removed, flowering glumes normal.....	12	110	9.1	40.40	8.73	21.60
Awns removed, flowering glumes clipped to 7-8 mm.....	9	85	9.0	32.82	16.31	49.69
Awns removed, flowering glumes clipped to 4-5 mm.....	17	117	6.8	20.85	28.28	135.63

\*Normal flowering glumes 10-12 mm long.

†All differences in the summary are differences from the normal.

It has been shown by Harlan and Anthony (1) and by Rosenquist (3) that the removal of the awn on heads of barley and wheat decreased the average weight of seed. It has been further shown by the data presented here that other kinds of mutilation also reduce the average weight of seed compared with that of seed produced in unmutilated flowers.

From the data presented in this paper a general conclusion may be stated as follows: When a high percentage of well-developed seed

from cross-fertilization is desired, the least possible degree of injury in emasculation should be the primary objective of the operator and opening the flowers by slitting the glumes seems more nearly to meet this objective than when the flowers are opened by cutting off the tips of the lemmas and paleas.

#### SUMMARY

1. Barley flowers were opened for emasculation and cross-pollination in two ways, *viz.*, (a) the lemmas and paleas of the flowers were cut off just above the tips of the anthers, and (b) the lemmas were slit. Slitting the lemmas resulted in the production of 21.5% more crossed seed and 10.8% heavier crossed seeds than where the tips of the lemmas and paleas were cut off.

2. Different methods of mutilating barley flowers and permitting them to self-fertilize resulted in differences in the average seed weight. The methods of mutilation and the average seed weights were as follows: Normal flowers (awns left on and glumes normal), 49.13 mg; awns left on, flowering glumes slit, 41.65 mg; awns removed, flowering glumes normal, 40.4 mg; awns removed, flowering glumes clipped to 7 to 8 mm, 32.82 mg; and awns removed, flowering glumes clipped to 4 to 5 mm, 20.85 mg.

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## QUANTITY AND RELATIONSHIPS OF CERTAIN ELEMENTS IN MICHIGAN LEGUME HAYS<sup>1</sup>

C. E. MILLAR<sup>2</sup>

A LARGE number of data relative to the chemical composition of alfalfa, sweet clover, and red clover have been collected in the past 13 years by the Soils Section of the Michigan Agricultural Experiment Station. Although portions of these data have been published, no attempt has been made to compile or correlate the results of the various studies. This paper attempts to summarize all such data and to interpret the results statistically.

As the primary object of the paper is to present these findings from a mathematical standpoint, it is unnecessary to dwell upon the experimental methods employed in collecting the data. Detailed procedures and data may be found in the indicated references. It should be mentioned, however, that the plant samples were placed directly in bags in the field, and hence were not subject to loss of parts or to chemical changes resulting from handling, curing, and storage in the hay-making process.

In interpreting the results, the popular "coefficient of linear correlation" and its "standard error of prediction" are used. Experimental significance is attributed to the results in which the correlation coefficient is greater than twice its standard error. Less difference is considered insignificant because it might have been due to chance or experimental error alone. In the discussions, free use is also made of Student's odds method to show significance, odds of greater than 20:1 being considered significant.

### CONTENT OF CERTAIN NUTRIENT ELEMENTS IN MICHIGAN ALFALFA HAY

Table 1 shows the average percentage of N,  $P_2O_5$ ,  $K_2O$ ,  $CaO$ , and  $MgO$  contained in Michigan alfalfa. The number of samples analyzed is also shown. The plants were grown on various soil types. Seasonal variation was smoothed out by selecting samples over a period of 13 years. Some plants received fertilizer, others none. Some were cut early, some cut late. Soils varied from neutral to strongly acid, with various quantities of lime applied. The analyses herein considered are in effect then a random sampling of Michigan alfalfa, and may be justifiably considered as representative of such. The data show Michigan-grown alfalfa to be higher in nitrogen, phosphorus, calcium, and

<sup>1</sup>Contribution from the Soils Section, Michigan State College, East Lansing, Mich. Approved for publication by the Director as journal article 301 n. s. of the Michigan Agricultural Experiment Station. Received for publication March 1, 1938.

<sup>2</sup>Professor of Soils. The analyses on which this paper is based are the work of several former members of the Soils Section. The writer is indebted to Mr. A. Mick, graduate assistant and Mr. W. Andrews of the Mississippi Station, former graduate assistant, for the compilations and assistance in preparation of the paper.

magnesium than average alfalfa hay of the United States as reported by Morrison.<sup>3</sup> On the other hand, the content of potassium is lower.

TABLE 1.—Quantities of nutrients contained in Michigan alfalfa grown on heavy and light soils and in average alfalfa hay for the United States.

Constituent	Heavy soil			Light soil			Difference		Average for U. S.*
	No. of samples	Mean %	S. D. of mean	No. of samples	Mean %	S. D. of Mean	%	S. D.	
N	71	3.33	±.062	103	2.95	±.045	0.37	±.077	2.35
P <sub>2</sub> O <sub>5</sub>	75	0.69	±.020	109	0.54	±.014	0.15	±.024	0.48
K <sub>2</sub> O	74	2.04	±.102	30	1.35	±.079	0.69	±.12	2.43
CaO	76	2.57	±.066	119	3.21	±.110	0.64	±.13	2.00
MgO	74	0.65	±.0151	40	0.75	±.040	0.10	±.043	0.43

\*From Morrison's "Feeds and Feeding".

During many years of field experimental work, it has been observed that fertilizer is more essential for an abundant growth of alfalfa on light than on heavy soils. The statistical data presented in the two divisions of Table 1 offer one explanation of this observation. The heavy soil group includes Brookston, Miami, Kewanee, and Hillsdale, as compared to the lighter soils, Fox, Coloma, Rubicon, Mancelona, and Plainfield. That differences in composition are highly significant is shown by the fact that difference in the means far exceeds twice the respective standard deviation in every case. The large number of samples analyzed strengthens this conclusion. It is interesting to note that alfalfa grown on heavy soil contains more N, P<sub>2</sub>O<sub>5</sub>, and K<sub>2</sub>O, but less CaO and MgO than that grown on light soil. In the first group of soils lime occurs much nearer the surface in the profile than in the latter group. Very little alfalfa is grown on the lighter soils without application of lime, but on the heavy soils mediocre to good crops are obtained in many cases without lime.

#### RELATIONSHIPS BETWEEN NUTRIENT ELEMENTS IN ALFALFA HAY

Table 2 shows the relationships which exist between the quantities of nutrient elements contained in alfalfa hay.

Using 147 random selected analyses, it was found that the nitrogen content is closely associated with the phosphorus content, the correlation coefficient being 0.75 with a standard error of  $\pm .036$ . This positive correlation indicates that the relationship between the percentages of these two nutrients is direct, that is, the nitrogen content increases as the phosphorus content increases, and *vice versa*. The small standard error of prediction indicates, moreover, that the scatter about the line of best fit is relatively small. This obvious association between nitrogen and phosphorus is, however, no more than is to be expected, for both are constituents of several proteins in a fairly fixed ratio. If the total percentage of both were confined to these

<sup>3</sup>MORRISON, F. B. Feeds and Feeding. New York: Morrison Pub. Co. Ed. 20. 1936.

proteins then the correlation coefficient would more closely approach 1.00. That it fails to do so is due, of course, to the fact that other forms of nitrogen and phosphorus are present in the plant tissue—forms in which they are not so definitely related or perhaps forms in which the association may be inverse.

TABLE 2.—*The relationship of certain of the nutrient elements in alfalfa hay grown in the field.*

Factors being correlated		Number of samples	Coefficient of correlation	Standard error of prediction	Constants	
x	y				a	b
N	P <sub>2</sub> O <sub>5</sub>	147	+ .75	± .036	-0.232	0.263
N	K <sub>2</sub> O	77	+ .50	± .086	-0.467	0.756
N	CaO	159	- .33	± .071	4.943	0.633
N	MgO	85	+ .30	± .099	0.420	0.073
K <sub>2</sub> O	P <sub>2</sub> O <sub>5</sub>	88	+ .43	± .088	0.528	0.088
MgO	P <sub>2</sub> O <sub>5</sub>	87	+ .41	± .090	0.410	0.392
CaO	P <sub>2</sub> O <sub>5</sub>	167	- .41	± .065	0.823	-0.074
CaO	MgO	98	- .28	± .093	0.859	-0.059
CaO	K <sub>2</sub> O	91	- .21	± .101	2.494	-0.206

Positive correlation coefficients are also evident between nitrogen and potassium; between nitrogen and magnesium; and between phosphorus, potassium, and magnesium, although the relationships are not so obvious as that above. These positive correlations also mean that the percentages of both members of the above pairs are either high or low. The lower values of the coefficient, however, indicate that the relationship is not great; and in addition, the large standard error of prediction values indicate that the scatter of the plotted points around the line of best fit is more widespread than in the nitrogen-phosphorus relationship.

The remaining nutrient pairs in Table 2, nitrogen-calcium, calcium-phosphorus, calcium-magnesium, and calcium-potassium, all have a negative correlation. This means that instead of both members of the pair being either low or high, the relationship is opposite or inverse. For instance, as the percentage of nitrogen rises the percentage of calcium in the tissue falls; or if the percentage of nitrogen is low, the calcium content is apt to be high. These relationships, however, are even less marked than those with positive coefficients. This is shown by the smaller value of the coefficient and the increasing magnitude of the respective standard error of prediction. The last case, in fact, shows so small a difference between the correlation coefficient and its standard error as to be practically insignificant. The relationship here is extremely doubtful, if existing at all. A graph of the percentage values would show a widespread scatter, while the location of the line of best fit would be very vague.

The relationships between quantities of the nutrient elements in alfalfa found in this study are in general agreement with the relationships found in woody plants by several investigators.<sup>4</sup>

<sup>4</sup>Data summarized in Fundamentals of Fruit Production by Gardner, Bradford, and Hooker (pages 130-160).

Table 2 is of value as it shows the effect of changing the percentage of one constituent on the percentages of other constituents. For example, the usual purpose of fertilizing soil for an alfalfa crop is either to increase the yield or to improve the hay quality by producing a change in the percentage of one or more constituents. If the protein content of alfalfa were increased by inoculation or soil treatment, it might be convenient to predict the effect of the increase on the percentages of other nutrients present.

For convenience, in the last two columns of Table 2 are the constants to substitute in the equation  $Y = a + bx$  for determining the probable percentage of one element in plant tissue when the percentage of another is known. If the percentage of one nutrient element ( $x$ ) is known, the percentage of the other ( $y$ ) may be estimated by substituting the proper constants. For the nitrogen-phosphorus relationship, substitution gives  $Y = -0.232 + 0.263 x$ , or percentage of phosphorus =  $-0.232 + 0.263$  (percentage of nitrogen).

#### EFFECT OF LIMING THE SOIL ON THE PHOSPHORUS CONTENT OF ALFALFA LEAVES

The data in Table 3 indicate that all applications of lime decreased the phosphorus content of alfalfa leaves. These decreases are significant as indicated by Student's odds. It should be noted, however, that the small application resulted in as large a decrease as did the heavy applications. The odds that 12,500 pounds of limestone decreased the phosphorus content more than any other application are only 5:1 which is insignificant. The obvious conclusions are that applications of lime decrease the phosphorus content of alfalfa and that small applications are just as effective as large ones.

TABLE 3.—*The effect of liming the soil on the phosphorus content of leaves of alfalfa grown in the field on Isabella sandy loam.*

Ground limestone per acre, lbs.	Number of comparisons	Increase in percent- age $P_2O_5$ due to lime	Student's odds
552	20	-0.123*	5999:1
2,000	20	-0.117	832:1
6,000	20	-0.117	1916:1
12,500	20	-0.149	2499:1

\*Decrease shown as negative increase.

The data on which Table 3 is based were taken from "Effects of Soil Type and Soil Treatments on the Chemical Composition of Alfalfa Plants" by A. L. Grizzard in this JOURNAL Vol. 27, pages 81-99). The same is true of the data in Table 4, and portions of that in Tables 5 and 6.

#### EFFECT OF APPLICATION OF SUPERPHOSPHATE TO MONTCALM SANDY LOAM ON PHOSPHORUS CONTENT OF GREENHOUSE-GROWN ALFALFA

From the data in Table 4 it is seen that of the three rates of superphosphate application only the two heaviest significantly raised the

phosphorus content of alfalfa hay. The third and fourth cuttings, moreover, seemed influenced more by the treatments than the first two. No effect on plant composition was observed from lighter phosphate application (data not shown). Definite conclusions should be avoided, however, in considering this table because the trials are so few in number that mathematical significance is doubtful. The figures are of value in that they show a tendency, but more definite statements are not justified by the data.

TABLE 4.—*The effect of the application of superphosphate to Montcalm sandy loam on the phosphorus content of greenhouse-grown alfalfa hay.*

Number of trials	Super-phosphate per acre, lbs.	Increase in percentage $P_2O_5$			
		First and second cuttings		Third and fourth cuttings	
		Mean	S. D.	Mean	S. D.
3	1,200	-0.017	$\pm 0.0219$	-0.027	$\pm 0.0548$
3	2,400	0.017	$\pm 0.0145$	0.103	$\pm 0.045$
3	4,800	0.140	$\pm 0.0436$	0.417	$\pm 0.0714$

#### EFFECT OF SUPERPHOSPHATE FERTILIZATION ON PHOSPHORUS CONTENT OF FIELD-GROWN LEGUME HAY

The phosphorus content of alfalfa hay grown in the field was not significantly affected on either the heavy or the light soils by applications of superphosphate (Table 5). Statistical analysis of the data from one study showed that the phosphorus content of alfalfa leaves was very slightly increased by superphosphate applications. An increase of 0.02% was found with odds of 20:1 which is on the border line of significance. There is, then, a tendency towards an increase of phosphorus content through using superphosphate fertilizer.

TABLE 5.—*The effect of superphosphate fertilization on the phosphorus content of field-grown legume hays.*

Soil	Plant	Number of comparisons	Increase in percentage of $P_2O_5$	Student's odds
Heavy: Brookston, Miami, Kewanee, and Hillsdale..	Alfalfa hay	11	0.073	8:1
Light: Fox, Coloma, Plainfield, Rubicon, and Manacelona.....	Alfalfa hay	17	-0.029	4:1
Heavy: Brookston, Gilford, and Miami.....	Alfalfa leaves*	12	0.063	94:1
Light: Isabella.....	Alfalfa leaves*	25	0.005	2:1
All soils.....	Red clover hay	5	0.150	211:1
All soils.....	Sweet clover hay	6	0.163	43:1

\*See footnote to Table 3.

Red clover and sweet clover show a great response to superphosphate applications. The phosphorus content of the former was in-

creased 0.15% with odds of 211:1, which is highly significant. Sweet clover showed a similar increase. Here again, however, the number of samples taken is so small that the results are questionable. They can be safely interpreted only as tendencies.

#### EFFECT OF POTASH FERTILIZATION ON THE PHOSPHORUS CONTENT OF FIELD-GROWN LEGUME HAYS<sup>5</sup>

Potash applications did not greatly affect the phosphorus content of alfalfa hay (Table 6). The phosphorus content of the leaves of alfalfa grown on Isabella sandy loam was significantly decreased. In this connection it is interesting to note that potash usually increases the yield on this soil type.

The phosphorus content of red clover hay was not affected by potash application, but a significant decrease in the phosphorus content of sweet clover hay was noted.

TABLE 6.—*The effect of potash fertilization on the phosphorus content of field-grown legume hays.*

Soil	Plant	Number of comparisons	Increase in percentage of $P_2O_5$	Student's odds
Light: Fox, Coloma, Rubicon, Mancelona, and Plainfield.	Alfalfa hay	11	-0.005	—
Heavy: Brookston, Miami, Hillsdale, and Kewanee.	Alfalfa hay	10	0.017	2:1
Light: Isabella.	Alfalfa leaves*	25	-0.074	506:1
Heavy: Brookston, Miami, and Gifford.	Alfalfa leaves*	12	-0.004	—
All soils.	Red clover	7	0.001	—
All soils.	Sweet clover	9	-0.092	138:1

\*See footnote to Table 3.

#### SUMMARY AND CONCLUSIONS

A statistical study of the effect of fertilization on plant composition and of the interrelationships of nutrient elements in alfalfa, sweet clover, and red clover hay, based on analyses of these plants accumulated during a 13-year period, warrants the following conclusions:

1. Nitrogen and phosphorus contents correlated closely.
2. Nitrogen-potassium, potassium-phosphorus, magnesium-phosphorus, and magnesium-nitrogen contents all showed positive relationships.
3. Calcium-phosphorus, nitrogen-calcium, calcium-magnesium, and calcium-potassium contents all showed inverse relationships.
4. The phosphorus content of alfalfa hay grown on heavy soils was higher than that of hay grown on light soils.

<sup>5</sup>A review of literature on the effect of various treatments on the phosphorus content of alfalfa may be found in "Effects of Soil Type and Soil Treatments on Chemical Composition of Alfalfa", by A. L. Grizzard, Jour. Amer. Soc. Agron., 27: p. 81-91. 1935.



5. Superphosphate applications did not change the phosphorus content of field-grown alfalfa hay.
6. Superphosphate fertilization showed a slight tendency to increase the phosphorus content of alfalfa leaves grown on light soil.
7. Large applications of superphosphate increased the phosphorus content of greenhouse-grown alfalfa hay.
8. The phosphorus content of field-grown red clover and sweet clover was increased by superphosphate fertilization.
9. Limestone applications reduced the phosphorus content of alfalfa.
10. Potash applications tended to increase the phosphorus content of alfalfa, did not effect the phosphorus content of red clover, and decreased the phosphorus content of sweet clover.

## CORRELATION OF THE WORK OF THE EXPERIMENT STATION AND THE EXTENSION AGRONOMIST IN DEVELOPING A SOUND EXTENSION PROGRAM<sup>1</sup>

J. S. OWENS<sup>2</sup>

IN the Land-Grant College system the agricultural teacher came first. He soon learned that he had little to impart except the traditions and even the superstitions which were the only existing bases for farm practice. It is not surprising that these were soon found inadequate. A demand for a more satisfactory body of teaching material was created and, before many years, acts creating special facilities for research were passed. Then, as a rule, the teacher's time was divided between teaching and research. Research had not been developed very far before farmers started demanding a larger portion of the time of the worker who already had two distinct duties. Although off-the-campus duties were confined chiefly to a few institute lectures, mainly during the winter period, they did give a direct farmer contact and this was reflected in the type of project selected for study, carried on chiefly through field trials.

With the passage of the Smith-Lever Act in 1914, most of the specialists for extension work, and even some county agents, were selected from those engaged in research. These men were familiar with the research of their time and even had first-hand acquaintance with much of the material which they were going to carry to the farmers.

The research workers who were not enticed to the new and flourishing pastures had fewer and fewer contacts with farmers. The sciences which are basic to agronomy grew rapidly and the research agronomist became further removed from the problems which were confronting farmers.

What happened to the extension agronomist? As farmers placed more confidence in his work, they demanded more and more of his time. The movement to make extension extremely popular and to reach every farmer immediately brought about highly organized and time-consuming methods of "putting over" extension. It became increasingly difficult to conduct research projects on the side, to maintain habits of systematic study, and even to keep one eye on the research related closely to his problems. Even more serious embarrassments followed. Research became more closely related to the pure science, e. g., studies of inheritance replaced variety trials. Research developed in so many directions that the extension worker not only found insufficient time to read the more important papers but found technic and theory becoming increasingly difficult to master.

While no satisfactory data are available it seems certain that at present subject matter specialization for extension usually follows the commodity interests. The agronomist endeavors to interpret the infor-

<sup>1</sup>Contribution from the Agronomy Department, Connecticut State College, Storrs, Conn. Also presented before the annual meeting of the Society held in Chicago, Ill., December 1 to 3, 1937. Received for publication March 3, 1938.

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mation relating to a crop, including crop improvement, soil management and fertilization, and often pest control, and then carries out a program covering the entire group of problems. This plan usually involves the fewest difficulties in developing and in conducting extension work. However, this seems inadequate criteria for measuring the value of a system.

In a few instances, the division for extension follows more closely the natural divisions which are recognized in the sciences. For instance, all of the plant disease work is under the guidance of a pathologist and he pays little attention to the crop divisions but crosses all, if need be. This system means a higher degree of specialization and should result in a more careful analysis of the problems and a closer approach to perfection in their solution.

There are also many instances of individuals combining extension with research and even residence teaching. There are research workers doing much effective extension work without direct assistance from extension organizations. The situation at a nearby substation merits description. The station is located near the center of a localized, high-value, cash crop industry. The worker in charge was chosen not only because of his capacity for productive research but also because he was to win and maintain farmer interest in the institution. Within a short time after the research was started farmers recognized its value and, since then, farmers flock to the institution with their problems. The workers are thus permitted to keep a close acquaintance with farm problems and to render a high type of extension teaching with a minimum of organized effort. The genius of this situation is that the same person can remain both the scholar and the teacher. It is what he has that draws the farmers to him and it is the opportunity for research which keeps him growing along with the farmers' problems. This illustration shows essentially the situation which existed before the development of specialized extension. Unfortunately, wide use of such a plan is impractical but possibly some of its values could be secured by other means.

We will now try to examine the possibilities for closer correlation between research and extension agronomy. Any conceivable solution presumes that the extension specialists are chosen because of scholastic ability and accomplishment equivalent to that of the research workers, and that both have equal opportunity for maintaining acquaintance with their respective interests. Myers (5)<sup>3</sup> has pointed out that extension has developed so rapidly that it has been difficult to develop the personnel needed. He further concludes that the extension specialist should have an educational background equal to that of the resident teacher and research worker. The Land-Grant College survey of extension work reported by Crocheron (2) states that the caliber of men in extension is inadequate and that more money will be needed to secure "adequate men".

The difficulty of maintaining a satisfactory grasp of agronomic information has already been mentioned in this paper and has been commented upon by Owens (6). Mighell (4), in reporting a study of

<sup>3</sup>Figures in parenthesis refer to "Literature Cited", p. 518.

professional improvement among agricultural economists, shows only 17 Land-Grant institutions out of the 47 replying that had any positive sabbatical leave system and only 20 leaves granted among 557 staff members during the years 1933-36. Nine of the 20 were in two universities. Furthermore, in 6 of the 17 states where there is a sabbatical system, extension workers are not eligible. He believes the discrimination against extension is due to over-centralization of the organizations. He also adds, "This is unfortunate since the nature of extension work in economics is usually such as to lead to a superficial grasp of problems unless one has opportunity for concentration not possible when actively engaged in routine affairs."

It is generally conceded that resident teachers need two to four months a year for physical recuperation and to reinforce their teaching material. Few extension workers have such opportunities. In addition, it has been considered good policy for teachers in agriculture to conduct some research, partially as a means of scholastic refreshment. Shinn (7), in reporting for a committee on instruction in agriculture in the Land-Grant colleges, states that in two colleges 100% of the teachers in agriculture give some of their time to research; in two others 90% or more do research and; among the 41 institutions reporting, 85.4% give some time to research. No similar information is available concerning the extent to which extension agronomists engage in research, but it undoubtedly would be much less.

The foregoing statements about sabbatical leaves and opportunities for research are given only to show that these means for professional improvement have not been so widely recognized as necessary for extension as for the other types of work. As a consequence, the extension worker may be handicapped in keeping pace with his colleagues.

The second fundamental for correlating the work in research and extension would seem to be a mutual understanding of the difficulties involved in the two types of work. Coffey (1) has analyzed this problem in some detail and suggests there should be some projects in the experiment station which in the course of completion call for cooperation with the extension forces. Myers (5) suggests that the remedy for research workers who do not appreciate extension is to go out and attempt to put across a piece of extension work. There appears to be an increasing recognition of the advantages in locating the extension specialist with the subject matter department. This affords frequent association which makes for understanding and appreciation.

With the assumption of good professional equipment and mutual appreciation, let us examine the possibilities for developing programs and conducting extension work.

For the first illustration, assume a hypothetical situation in an eastern state where dairying is important. Feed costs are high, whether purchased or grown on the farm, and yet there is an abundance of land which appears to be potentially good for pasture production. The farmer knows he is having trouble but cannot see the solution. Known methods for economic pasture improvement offer little hope to the extension worker. The research organization becomes interested and starts miscellaneous trials in an effort to determine what studies may become productive. The investigations lead on and

on. Finally, those who have conducted the investigations acquire knowledge and experience which give them an unusual understanding of pasture problems. Would it be possible to give the farmers a direct contact with these pasture experts and their enthusiasm—a product developed with the evolving pasture problem? They might be directly responsible for outlining the pasture program; yet, unless the research were projected into the variety of soil and climatic conditions and the many systems of management necessary on individual farms throughout the state, even the best application of the station findings would fall down.

Somewhere in this picture there must be a crossing of what is usually thought of as extension and as research. The extension specialist might enter as soon as the investigations show real promise. He might start supplementary experiments (no less scientific but probably less elaborate than those conducted at the station) to determine the modifications needed for practical use. This experience would give him an understanding which he would not get as a by-stander. Another choice would be for the station worker to conduct the supplementary experiments and thus remove the one limitation he would have for taking the extension load.

For the next illustration assume that there are several crops involved, including even some in the horticultural group. All of these are nearly alike with respect to the basic problems in nutrition and soil management, in improvement through breeding and selection, in disease and insect control. Each of these is now a highly specialized and difficult field and no one can be expected to be thoroughly acquainted with all of them. We will assume that there are known possibilities for improvement of the wheat crop. The geneticist brings his contribution into the extension program, or if he hasn't any special information, initiates a search. The workers in nutrition, disease, and insect control follow the same procedure. The frequent objection to the system just outlined is that it is impractical to carry out. This statement needs further examination. Seldom, if ever, would the entire group be working intensively with the same problems at the same time. It does seem to correct several of the faults of those in more common use. It narrows the scope of scientific interest and may be the only alternative as problems grow in number and in complicity. The significance of the accomplishment over a period of years might more than offset the mechanical difficulties involved.

The foregoing have been approached mainly from the point of view of the subject matter problems; or that of the research worker who has a body of specific information which he wishes to see utilized. The extension specialist who is a good observer also gets valuable information out of the farmers' experiences. The farmer presents his problem to him and he immediately attempts to find, not the final answer, but one which is better than the farmer's. He may draw upon many sources and evolve a solution. It is impossible for his own or neighboring institutions to have specific information for all of the problems he confronts. He must interpret and adopt from all available sources and not "extend" research in the narrower sense. All of these situations would indicate that the extension specialist needs all of his time for extension.

On the other side is the fact which has been recognized widely that the research worker needs the type of farm acquaintance which the extension specialist gets to orient and stimulate him. It appears appropriate to ask how much research should be built about the "practical" or more immediate farm needs. Certain research projects may be so distantly related to farm practice that correlation with the extension program is futile.

For the analysis here it is expedient to divide research into two categories, service and basic. While these terms have some unsatisfactory connotations they will do for the imaginary separation. The service or applied research might be combined with extension and the responsibilities divided as the personnel and other local situations necessitate. This would bring research and extension together into the same programs instead of, as sometimes happens, creating two divergent ones. It would remove the perplexing problem about when research information should be turned over to the extension service. After McCue (3) secured numerous statements on this matter from station and extension directors and from scientific workers, he concluded that too little attention was paid to trying out information after the research worker believed he had solved the problem.

The establishment of basic principles through more fundamental research is more remote from extension. The field may be so highly specialized and the technic so skilled that the worker can give little thought to the immediate use of his developments. Yet, in Land-Grant institutions it would seem that even basic studies should generally be aimed at improving very practical situations. The extension specialist may see the problems which require the basic research and should have opportunity to present them when research programs are planned. The extension worker conceivably could also have a part in determining what the investigation might mean for farm practice.

Irrespective of institutional organization the agronomist who is in contact with farmers must have a comprehensive fund of agronomic knowledge, and not musty at that. Glancing through summaries and abstracts does not give sufficient acquaintance with the literature. It is impossible to read the large number of original papers, many of which are voluminous and without special value. There is urgent need for the agronomists' preparing a series of monographs which would bring together all of the significant contributions, including interpretations for each of the major problems in the plant and soil sciences on which notable accomplishments have been made.

This would not be an easy task. The American Society of Agronomy could draw up a plan and seek support for it. The topics would need careful selection and the best talent in the field enrolled or possibly drafted. A special fund would be needed to release men from their regular duties and thus afford ample opportunity to do the type of summarization and interpretation needed.

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## SOIL CONSERVATION FROM A LAND-USE VIEWPOINT<sup>1</sup>

J. S. CUTLER<sup>2</sup>

PROPER land use is essential to an adequate soil conservation program on agricultural lands, but soil conservation cannot be achieved through land use alone. Soil conservation in the broadest sense implies maintaining the productive capacity of the land over relatively long periods. To achieve soil conservation not only requires that land be used for the purpose for which it is best suited but also necessitates the adoption of such soil conservation practices as are required for each kind of land. In other words, soil conservation and land use are intimately related but not synonymous. An attempt will be made to discuss the various interrelationships between proper land use and adequate soil conservation.

### SOIL CONSERVATION VERSUS SOIL DETERIORATION

Obviously, soil conservation is the opposite of soil deterioration, but in order fully to understand the problems involved in soil conservation, it is desirable to give attention to those processes or practices that result in soil deterioration.

*Reduction in mineral nutrients.*—Throughout various sections of the United States, minerals are being removed continuously from the surface soil through leaching and crop removal. Obviously the reduction of mineral constituents of the soil is more rapid in a cash-grain farming than in a livestock farming system. This continual drain of the mineral nutrients from the soil necessitates the use of various fertilizers and liming materials.

*Decline in organic matter.*—Organic matter in the soil increases most rapidly under a grass cover. The plowing and tilling operations in the production of cultivated crops result in a continuous and fairly rapid reduction in the organic matter content of the soil. The growing of a large proportion of cultivated crops in relation to sod crops accelerates this reduction. Changing the crop rotation to bring about a better balance between the sod, or soil conserving crops, and the cultivated or soil depleting crops retards the decline. Bradfield<sup>3</sup> has shown that 40 years' cropping on Nappanee soil in Paulding County, Ohio, has increased the weight of soil per cubic foot, in the first foot from 65.5 pounds (in virgin soil) to 81.7 pounds. The pore space, expressed as percentage of the total volume, has declined from 60.3% to 50.5%. The organic matter content has declined from 132,000 pounds per acre in the virgin soil to 89,400 pounds in the soil cropped for 40 years. The lengthening of the crop rotation by including more years of meadow or rotation pasture results in the land being plowed and

<sup>1</sup>Contribution from the Soil Conservation Service, U. S. Dept. of Agriculture, Dayton, Ohio. Also presented at Summer Meeting, Corn Belt Section, American Society of Agronomy, June 1937. Received for publication March 7, 1938.

<sup>2</sup>Regional Conservator, Region 3.

<sup>3</sup>BRADFELD, RICHARD. Our heritage, the soil. Ohio State Univ. Agr. Ext. Serv. Bul. 175. 1936.



worked less frequently, thus retarding the rapid downward trend in organic matter content.

*Impairment of physical condition of the soil.*—To achieve good tilth, attention must be given to the moisture content of the soil at the time it is plowed or during the preparation of the seedbed. Working the heavier soils when they are too wet is likely to result in disastrous effects to the physical condition of the soil. Observations in northwestern Ohio point very definitely to a cumulative impairment of physical condition as a result of working the soil when too wet.

*Erosion.*—Recently erosion has been recognized as a most significant soil-deteriorating process. Under many conditions it has a greater effect on the productive capacity of the soil than all other deteriorating processes combined.

Recent studies of erosion on the long-time fertility plats at the Ohio Agricultural Experiment Station show considerable soil losses. By carefully measuring the depth of the soil horizons and the distance from the surface and comparing these measurements with uneroded soils, it has been possible to estimate in a systematic way the amount of soil lost by erosion.

Estimates<sup>4</sup> on plats cropped continuously in corn since 1894 on land with a slope ranging from 2 to 4% show an average soil loss of about 8.9 inches. Over most of this section of plats the B horizon has been turned up in plowing, indicating that at least two-thirds of the surface soil (A horizon) has been washed away. It is evident that the plow soil of today is quite different from that of 40 years ago. On the continuous oats plats, it is estimated that the soil loss for the section as a whole is 5.2 inches. The estimates for the annual average soil losses are 35 tons per acre per year for corn and 19 tons per acre per year for oats.

These studies of erosion on long-time fertility plats are of especial interest, since they agree closely with the results obtained more recently by the Soil Conservation experiment stations and serve to increase confidence in the results which these stations have obtained in the short period since their establishment. The National Resources Board<sup>5</sup> reports that erosion and leaching combined are responsible for 85.6% of the annual losses of plant food elements from the soils of crop and pasture areas of the United States. Of this loss 65% is from crop land and 20.6% from pasture. Grazing animals and harvested crops account for the removal of only 14.4% of the nitrogen, phosphorus, potash, calcium, magnesium, and sulfur lost annually.

#### LAND USE AS APPLIED TO AGRICULTURAL LANDS

From a land-use viewpoint, agricultural lands can be classified conveniently into crop lands, grasslands, and woodlands and are here defined as follows:

*Crop lands.*—Crop lands are lands regularly used for the production of cultivated crops, including rotation meadows and pastures, which at some time or other in the rotation are used for cultivated crops.

<sup>4</sup>CONKEY, and BURRAGE. Erosion losses of soil from soil fertility plats. Ohio Agr. Exp. Sta. Bul. 561. 1936.

<sup>5</sup>National Resources Board Report. December 1, 1934.

*Grasslands.*—Under grassland is included permanent pasture or that which continues in grass for periods in excess of 5 years. Permanent meadows are also included—in other words, land which is not used for cultivated crops but only for the production of grasses and legumes either as pasture or hay.

*Woodlands.*—Woodlands include those lands utilized for the growing of trees and shrubs and the production of forest products.

#### FACTORS INFLUENCING LAND USE

In determining proper land use, such factors as soil, slope, erosion, cover, and field location, as well as certain economic factors, must be considered.

*Soils.*—Soils vary considerably in their native fertility and in their physical structure, factors which are expressed by the soil type. The physical structure of the soil affects its natural crop adaptations, ability to resist erosion, and ease of tillage. The native fertility of the soil determines to a large extent its productive level, as does also the manner in which the soil type responds to applications of fertilizer or liming materials. Obviously, many of the soil characteristics are interrelated as far as their effect on land use is concerned. Generally speaking, soils with a high productive level favor both plant root and top growth, and this greater growth in turn assists in the prevention of soil erosion through the increased binding effects upon the soil.

*Slope.*—The slope of the land largely determines the practicability of cultivation. Erosion losses are greater on steep slopes and drainage difficulties are increased with lack of slope. The length of the slope largely determines volume of run-off water. Experience has shown that certain slopes can be used for the production of cultivated crops, provided soil conservation practices are followed, while other steeper slopes are suited only for meadow or pasture and still others only for woodland.

*Degree of erosion.*—The present condition of the soil so far as erosion is concerned must be considered in determining proper land use. Degree of erosion is usually expressed in terms of the amount of topsoil that has been removed. Generally speaking, the productive capacity of any given field will vary directly with the depth of the surface soil. Thus, the amount of soil remaining in a given field provides a rough indication of the crop-producing power of the particular soil or soils.

Gullies may make cultivation impracticable and may thereby alter land use. The depth, width, and cross section of the gullies and their frequency determine the degree to which they will impede cultivation. Obviously, the more serious the gullying the greater the improvement costs will be if such lands are to be used for the production of crops or grasses. Hence, it is desirable that badly gullied lands be used permanently for woodland.

*Plant cover.*—The present cover of a given tract of land must be taken into account in land-use planning. In many parts of Region 3 relatively level lands are used for woodlands and crops are grown on sloping lands. From a long-time point of view it is desirable that these

more level lands be utilized, where possible, for crop production and that the steeper lands, already more eroded, be used permanently for woodland. Such a change must, of course, be accomplished gradually. If a land owner depends on products from his woodlands, it is highly essential that the steeper, eroded lands be reforested and given time to develop into productive woodlands before the present woodlands are cleared for crop production.

*Present field location.*—From a practical standpoint, many fields are not now located so as to permit the best use of land. Usually the length of the field determines the direction of the major cultural operations, no attention being paid to actual topography in the field. Too many fields throughout the Corn Belt show the disastrous effects of cultivation practiced up and down the slope. Originally many fields were laid out parallel to the line fences rather than with respect to topography, and no thought was given to soil conservation. There is ample evidence to show that "square" farming is not suited to a "round" country.

*Economic factors.*—The nature and location of markets, in part determine land use. Usually dairying is centered around major cities. Special local markets may make it desirable to produce special crops. Fruit and truck crops frequently are grown on lands not especially adapted to these crops, but their nearness to market makes such use fairly profitable.

In the poorer parts of Region 3 the necessity for economic returns from the land frequently causes some of the poorer farm lands to be put to uses to which they are not primarily suited. Under these conditions, yields are usually low. Some owners are so concerned in making a living that they cannot consider the effect of such misuse of land on the future productive capacity of the agricultural lands of this nation. A few farms have been found that have no land suited for field crop production. Here the land should be devoted entirely to grass and tree crops if the soil is to be preserved. However, the present owners require a certain acreage of cultivated crops and this results in improper land use.

#### RELATION OF SOIL CONSERVATION AND LAND USE

With respect to soil and slope certain lands may be suited, for example, to grass but the soil on these lands will be lost, even under appropriate land use, unless soil conservation practices such as liming and contour furrowing are followed. We might, for example, prepare recommendations of land use based on present farming methods. The areas suited to crops would be located largely on level lands, but these level lands are now showing marked evidence of deterioration through unwise cropping practices. It is essential that we adopt all known soil conservation practices and measures.

Recently the Soil Conservation Service estimated the acreage of the agricultural lands suitable for the production of cultivated crops in each state in this region. For example, in Kentucky, the census shows a total of 6,873,500 acres now in cultivation. Of this acreage only 1,598,800 acres, or 23.3%, is suitable for cultivation without satisfactory erosion control practices. In addition, it is estimated that

there are 487,600 acres now in pasture that are suitable for cultivation and 251,600 acres in brush or timber that might be cleared and utilized for tillable crops. In other words, a total of only 2,338,400 acres are actually suitable for cultivated crops under the present erosion-inducing cropping practices.

If, however, the best known soil conservation practices are followed, 5,234,100 acres, or 76.1% of the acreage now in cultivation, could be satisfactorily used for tillable crops in rotation. To this may be added the acres now in pasture and woodland suitable for cultivation under the best known soil conservation practices, making a total of 8,757,700 acres potentially tillable, or 1,884,200 acres more than are now in cultivation. To utilize this potentially tillable acreage requires not only proper land use, but the adoption and continuation of the best known soil conservation practices. These data are summarized in Table 1.

TABLE 1.—*Acreages of agricultural lands in Kentucky and Ohio suitable for the production of cultivated crops.*

Present status of land	Acreage reported in 1930 census	Land suitable for cultivation	
		Under present practices, acres	Under best soil conservation practices, acres
Kentucky			
Land now in cultivation . . . . .	6,873,500	1,598,800	5,234,100
Land now in permanent pasture . . . . .	6,740,782	487,600	2,708,900
Land now in brush or timber . . . . .	5,421,246	251,600	814,700
Land in need of drainage . . . . .			
Ohio			
Land now in cultivation . . . . .	10,690,035	6,827,120	11,697,020
Land now in permanent pasture . . . . .	6,788,014	1,386,560	2,943,210
Land now in brush or timber . . . . .	3,158,882	450,770	694,570
Land in need of drainage . . . . .		12,740	12,740

To express the situation in another way, only 4 of the 120 counties in Kentucky have more than 25% of the land suitable for cultivation without erosion control, whereas in 71 counties only from 2 to 7% of the land is suitable, as shown in Table 2.

TABLE 2.—*Agricultural lands in Kentucky suitable for cultivation without erosion control.*

Percentage of land	Number of counties
2-7 . . . . .	71
7-15 . . . . .	37
15-25 . . . . .	8
Above 25 . . . . .	4

However, if the best known erosion-control practices are followed, an entirely different situation would prevail, as indicated in Table 3.

TABLE 3.—*Agricultural lands in Kentucky suitable for cultivation with erosion control.*

Percentage of land	Number of counties
0-15.....	34
15-34.....	32
35-50.....	28
50-69.....	20
70 and over.....	6

Studies in the other states in Region 3 show similar trends.

#### ACTUAL VERSUS IDEAL LAND USE

Studies of the actual and ideal land use have been made on the Salt Creek and Indian Creek projects in Ohio. Table 4 shows the distribution of the acreage of these projects with respect to the five slope classes and the actual and ideal percentages of the total area in crops and pasture.

TABLE 4.—*Actual and ideal land use for the Indian Creek (Ohio) and Salt Creek (Ohio) Soil Conservation Service demonstration projects.*

Slope	Percentage distribution of the entire area with respect to slope classes	Percentage of total area in			
		Cultivated crop		Pasture	
		Actual	Ideal	Actual	Ideal
Indian Creek Project					
A (0-3%).....	28.9	22.9	28.9	3.5	0.0
B (3-8%).....	46.7	33.0	33.7	9.3	12.8
BB (8-15%).....	9.7	5.9	0.0	2.8	9.5
C (15-25%).....	6.7	0.7	0.0	3.4	0.0
D (over 25%)....	8.0	0.0	0.0	3.3	0.0
Totals.....	100.0	62.5	62.6	22.3	22.3
Salt Creek Project					
A (0-5%).....	14.2	7.6	14.2	5.4	0.0
B (5-12%).....	28.2	16.7	22.9	9.1	5.2
BB (12-20%)....	26.6	10.0	0.0	13.2	26.6
C (20-30%).....	12.5	2.4	0.0	7.4	10.6
D (over 30%)....	18.5	0.0	0.0	6.5	0.0
Totals.....	100.0	36.7	37.1	41.6	42.4

This table shows that 26% of the total area in the Salt Creek project lies on BB slopes. Whereas, ideally, no part of this area should be under cultivation, a little less than one-third of all crop land on the project lies on BB slopes. On the other hand, 14.2% of the total lies on A slopes and whereas all of this land should be under cultivation, only about half of it is cultivated. The table shows that in both

projects crops are grown on all except the D slopes, whereas ideally only slopes A and B should be cultivated. Lands adapted to crop production are not utilized to the best advantage, particularly in the Salt Creek project.

Normally all B slopes require erosion-control measures if they are to be used for crop production; while on all the BB slopes, erosion-control measures are not only absolutely essential, but longer rotations must be followed if serious soil losses are to be prevented. If it were possible to rearrange the crop lands of the Salt Creek project so that the more level lands were used for cultivated crops even in this hilly area of eastern Muskingum County, Ohio, no slope of more than 12% would need to be used for cultivation. Such a rearrangement would provide an adequate acreage of cultivated crops for the system of livestock farming now being followed. The same general situation exists with respect to the lands now devoted to pasture. Many pastures are now located on lands which are primarily adapted to forest. Under ideal use, 37.1% of the land would be devoted to cultivated crops, 42.4% to pasture, and 20.5% to forest. It is well recognized that this ideal land use cannot be accomplished, but experience shows that by careful analysis and thoughtful planning in the rearrangement of each individual farm much can be done to approach the ideal.

An analysis of land use on Indian Creek Soil Conservation project in Butler County, Ohio, shows that no slope over 8% would need to be cultivated as there is sufficient acreage of A and B slopes (0-8%) for the present acreage of cultivated crops.

The soil conservationist's problem is to adapt the land classification and specific soil-saving practices to the individual farm. No preconceived formula can be applied directly. The general considerations must be analyzed and adapted to the peculiarities of the farm, as a tailor takes yard goods and cuts it to fit the shape of the customer.

#### READJUSTING LAND USE ON THE INDIVIDUAL FARM

In attempting to readjust land use on an individual farm the first step is to determine whether the present fields are properly located or properly divided and whether relocations will bring about better land use. In the field or portion of the field under consideration certain physical characteristics of the land or plants growing upon it will be helpful in determining whether the field is being used correctly. Are there many so-called "galled-spots" or "clay-spots"? These usually indicate that erosion has removed a large proportion of the surface soil from these areas. Is the field laid out in such a way that the farming operations are on the contour or at least at right angles to the general slope direction?

In grasslands, does the topography permit the application of fertilizer and liming material with machinery and clipping with a mower? Is the depth of the soil to underlying rock so shallow that grasses tend to "burn out" during the summer months? What is the quality of the farm woods? Frequently wooded areas have been so heavily grazed and burned that they do not have an understory of young seedlings and young trees. Where the tree stands cannot readily be thick-

ened and the ground surface is already covered by grass, it may be desirable to remove the existing trees and devote the area to pasture. Other areas, through the prevention of fire and grazing will improve so as to make vigorously productive woodland in a relatively few years. If the situation in the entire farm has been thoroughly analyzed, by fields or parts of fields, a proper land-use plan for the particular farm may be formulated.

The need for pasture, crops, and woodland products on each farm is the second consideration. These needs will vary with the type of farming practiced, but the studies made thus far indicate that there is a minimum acreage desirable for each of these general classes on every well-planned farm. A study of the farms on the Leatherwood Creek Soil Conservation project, Bedford, Indiana, at the time of the initiation of operations in 1935 showed that the average acreage used per animal unit of livestock kept was 1.2 acres of feed grain,  $\frac{1}{2}$  acre of hay, and 2.4 acres pasture (excluding woods pasture). Acreages required for most efficient feeding of this livestock were estimated to be 0.8 acre of grain, 1.2 acres of hay, and 3.5 acres of average pasture. This contrast between present acreages and acreages required to meet efficient feeding needs, based on most recent experimental evidence, indicates that most livestock farmers entering into a long-time soil conservation program must adjust their feeding practices if feed supplies and livestock needs are to be brought into balance.

A specific example of the relationship between land use and feeding practice is found in experimental work conducted by the Trumbull County, Ohio, Experiment Station<sup>6</sup> recently. A ration of heavy hay-light silage was compared with heavy silage-light hay feeding. A high quality alfalfa-timothy mixture hay was fed. Translated into acreages, the heavy hay-light silage ration required approximately  $\frac{1}{2}$  acre of corn, or its equivalent, for each acre of hay. The high silage-low hay ration required approximately 1.9 acres of corn for every acre of hay. In the first case 33% of the land would be in depleting crops and 67% in conserving crops, while in the second case 67% would be in depleting crops and 33% in conserving crops in order to provide the feeds required. The effect upon soil conservation is obvious. In addition the return above feed costs was distinctly in favor of the heavy hay-light silage ration. The cow, the soil, and the pocket-book profited from heavy feeding of high quality hay.

Since it is generally recognized that it is more difficult to maintain a satisfactory soil conservation program under a cash-grain farming system than under a livestock system, a grain farming system should not be practiced on the more sloping lands. The increased difficulty of working some of the more level heavier lands has forced the inclusion of legumes in the crop rotation, with the result that the corn, corn, oats plan of grain farming is disappearing.

The third step is to determine those shifts in land use that are both feasible and practicable. Usually it will be found that certain adjustments either in field boundaries, row direction, or in present use, can be made immediately to bring about a better land-use program. Also

<sup>6</sup>MONROE, C. F., and ALLEN, HAROLD. Increased hay feeding for dairy cows. Ohio Agr. Exp. Sta. Bul. 538. 1934.

such a farm analysis provides a basis for future land-use readjustments.

After the land use has been determined, the adoption of better farming methods should be considered. Obviously the goal is to obtain a maximum production with minimum loss of soil and soil nutrients and at a reasonable production cost. This means the adoption and use of balanced crop rotations adjusted to the soil and slope of each field, including a good legume or legume-grass meadow. Certain erosion-control practices, such as contour strip cropping and terracing, must be followed on the crop lands. This may require adequate applications of fertilizer and lime. Pasture land should be contour furrowed to conserve moisture and reduce run-off. Such other measures as are necessary to control weeds must be used. In management of woodlands, careful attention must be paid to protecting them from fire and grazing and in following the selection method of cutting. These practices illustrate some of the problems in land-use readjustment on the individual farm.



## THE EFFECT OF ASSOCIATION OF RYE AND AUSTRIAN WINTER PEAS AND OF NITRATE OF SODA ON NITROGEN FIXATION<sup>1</sup>

W. B. ANDREWS AND MARVIN GIEGER<sup>2</sup>

LEGUMES and nonlegumes have been grown together in pastures and in cultivated fields for a long time. The value of the associative growth of legumes and nonlegumes was recognized by Lyon and Bizzell (9),<sup>3</sup> whose data show that the growth of alfalfa with timothy increased the protein content of the timothy.

Virtanen (12, 13, 14, 15) and his co-workers established the reason for the non-legume being benefited by the presence of the legume. They found that as much as 54 to 74% of the nitrogen fixed by the nodule bacteria on peas was excreted into the media in which the peas were growing and that barley took up 16 to 27% of the excreted nitrogen. In extreme cases the potato plant took up 10 times as much nitrogen as the legume in association whose yield was reduced. The excreted nitrogen was found to be 50% L-aspartic and the remainder "probably di-amino-acid (lysine)".

The effect of the ratio of legumes to nonlegumes has been investigated by Virtanen (12) and by Wilson and Wyss (17). In general, the yield of the legume is reduced if too many nonlegumes are grown with it. The excretion of nitrogen (14) has been found to be much greater in soil, sand, and Kaolin than in water media.

Virtanen (12) found that excretion of nitrogen takes place with red clover, white clover, and peas when good strains of bacteria were used. In addition to the presence of alfalfa increasing the protein content of timothy, Lyon and Bizzell (9) obtained similar results with timothy and oats when clover and peas, respectively, were grown with them. The results of Lipman (7) are similar to those of Lyon and Bizzell. Thornton and Nicol (11) found that rye grass obtained considerable quantities of nitrogen from alfalfa when they were grown together.

Nonlegumes are not always benefited by the associative growth of a legume. Lipman (7) found that soybeans reduced the yield of corn. Ludwig and Allison (8) obtained depressed yields of nonlegumes when grown in the presence of cowpeas, alfalfa, vetch, and sweet peas. Bond (4) and Stallings (10) did not obtain a benefit to nonlegumes when they were grown in the presence of soybeans. However, in Wilson and Wyss' (17) experiments, 23 to 60% of the nitrogen fixed by Manchu soybeans was excreted.

In pasture experiments Johnstone-Wallace (5, 6) found that the growth of wild white clover with Kentucky bluegrass in pasture plats increased the yield of the grass from 881 to 2,243 pounds per acre and the protein content from 18 to 25%.

Wilson and Burton (16) and Wilson and Wyss (17) have investigated the factors affecting the excretion of nitrogen by legumes. The former present a good review of the literature on the subject, showing that excretion of nitrogen by leguminous plants takes place in many cases and that often the yield and protein content of nonlegumes grown with legumes is increased to a marked degree.

<sup>1</sup>Contribution from the Department of Agronomy, Mississippi Agricultural Experiment Station, State College, Miss. Received for publication March 7, 1938.

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<sup>3</sup>Figures in parenthesis refer to "Literature Cited", p. 536.

In the winter of 1931-32 greenhouse experiments were set up to determine the effect of the association of rye and Austrian winter peas and of nitrate of soda on nitrogen fixation.

### EXPERIMENTAL

Austrian winter peas and rye were grown alone and together in 3-gallon earthenware pots. Twenty-five pounds of sandy loam soil were put into each pot. Seeds were planted in separate containers on November 18 and transplanted December 1, 1931. There were twice as many rye plants as Austrian winter pea plants in the pots. The pots containing both Austrian winter peas and rye contained the same number of rye plants and the same number of pea plants as when they were grown separately.

Nitrate of soda was applied at 0, 50, 100, 200, 400, and 800 pounds per acre. The nitrate of soda was applied in divided applications at approximately 2-week intervals until March 7.

The Austrian winter peas were inoculated with a good strain of nodule bacteria. An 0-8-4 fertilizer was applied to the soil in each pot at the rate of 2,400 pounds per acre.

The plants were harvested the first part of April at which time the Austrian winter peas were blooming. The smallest rye was in the bloom stage and the largest rye had not commenced to bloom.

In harvesting, the tops were removed just above the level of the ground and the soil was thoroughly wetted. The roots were then worked out of the soil after which they were washed as free of soil as convenient in clean water. As reported in a previous paper (3), where soybean roots are concerned, it is practically impossible to remove the soil from the roots to a uniform degree. The yield and percentage of nitrogen of the roots are therefore reported with a uniform ash content of 8%. The yield and percentage of nitrogen data of the tops are reported on the air-dry basis.

Nitrogen determinations were made on the soil at the beginning and at the end of the experiment. The nitrogen determinations were made according to the official methods.

In presenting the data the yields, percentage of nitrogen, total nitrogen, and amount of nitrogen fixed are presented for each treatment. To determine the effect of the association of rye and Austrian winter peas, the data were paired according to nitrogen treatment and averages and average differences were calculated. Student's odds for significance were used with the paired data. There were 19 pairs of data in these cases.

### RESULTS AND DISCUSSION

#### EFFECT OF ASSOCIATION OF RYE AND AUSTRIAN WINTER PEAS AND OF NITRATE OF SODA ON YIELD OF AUSTRIAN WINTER PEAS AND RYE

The 400- and 800-pound rates of nitrate of soda reduced the yield of Austrian winter pea tops and roots significantly when grown alone (Table 1). The yield of the roots was  $6.9 \pm 0.59$  grams per pot without nitrogen treatment and  $3.8 \pm 0.59$  grams per pot with 800 pounds of nitrate of soda per acre. Intermediate rates of nitrate of soda produced intermediate reductions in root growth. Even though the higher quantities of nitrate of soda reduced the yield of the peas when

grown with rye, the differences are not statistically significant. Each increase in nitrate of soda applied increased the yield of the rye tops when grown alone and when grown with Austrian winter peas. The higher quantities of nitrate of soda reduced the yield of roots when rye was grown alone.

TABLE 1.—*Effect of association of rye and Austrian winter peas and of nitrate of soda on yield of Austrian winter peas and rye in grams per pot.*

Pounds NaNO <sub>3</sub> per acre	Austrian winter peas, grams	Rye, grams	Roots, grams	Total, grams
Austrian Winter Peas Grown Alone				
None	68±5.8†	—	6.9±0.59	75±5.8§
50*	54±3.8	—	5.3±1.25	59±4.0
100	59±5.6	—	5.8±1.33	65±5.8
200	75±5.2	—	4.0±0.64	79±5.2
400†	52	—	3.5	56
800*	45±5.1	—	3.8±0.59	49±5.1
Austrian Winter Peas and Rye Grown Together				
None	54±9.1	12±0.4	15.0±2.98	81±9.6
50*	62±3.8	13±1.0	13.2±0.89	88±4.0
100	49±6.8	16±1.1	11.7±1.95	77±7.2
200*	53±3.4	19±1.5	12.2±1.01	84±3.9
400	45±7.7	28±3.6	10.9±0.15	84±8.5
800*	43±7.8	29±0.8	9.1±1.58	81±8.0
Rye Grown Alone				
None	—	16±1.3	6.7±0.55	23±1.4
50	—	17±1.0	7.4±0.55	24±1.1
100	—	23±1.6	12.7±1.92	36±2.5
200	—	27±1.5	9.8±1.47	37±2.1
400	—	33±2.4	12.6±1.53	46±2.9
800	—	50±9.4	12.3±1.65	62±9.5

\*Average of three pots instead of four.

†Average of two pots instead of four.

‡Standard error

§The standard error of the total equals the square root of the sum of the squares of the standard errors of the figures added.

The yield of tops and roots of Austrian winter peas and rye grown together (Tables 1 and 5) was greater in every case than either grown alone. The yield of peas alone was 66 grams per pot and of peas and rye 83 grams per pot, the difference in favor of growing them together being 17 grams per pot. Austrian winter pea tops were 7 grams per pot less when grown with rye than when grown alone. The roots reduced the yield of the rye 8 grams per pot. These differences

and when grown with rye (Table 2). In general, increasing the nitrate of soda increased the percentage of nitrogen in the rye. When rye was grown alone, it had 0.77% nitrogen and 1.29% where none and 800 pounds of nitrate of soda were applied. Where peas were grown with rye, the corresponding percentages of nitrogen were 1.14 and 1.29%, respectively.

TABLE 2.—*Effect of the association of rye and Austrian winter peas and of nitrate of soda on the nitrogen content of Austrian winter peas and rye.*

Pounds NaNO <sub>3</sub> per acre	Percentage nitrogen in		
	Austrian winter peas	Rye	Roots
Austrian Winter Peas Grown Alone			
None	2.49±0.183‡	—————	3.98±0.196
50*	2.34±0.347	—————	4.18±0.466
100	2.33±0.236	—————	3.87±0.135
200	2.41±0.145	—————	4.21±0.335
400†	2.45	—————	3.10
800*	2.33±0.155	—————	3.15†
Austrian Winter Peas and Rye Grown Together			
None	2.86±0.070	1.14±0.060	2.91±0.193
50*	2.72±0.057	1.25±0.047	3.62±0.191
100	2.65±0.075	1.36±0.069	3.12±0.083
200*	2.94±0.101	1.21±0.097	3.22±0.080
400	2.43±0.143	1.40±0.070	2.68±0.187
800*	2.64±0.223	1.69±0.096	3.03±0.388
Rye Grown Alone			
None	—————	0.77±0.057	1.10±0.191
50	—————	0.82±0.067	1.36±0.115
100	—————	0.79±0.040	0.93±0.104
200	—————	0.90±0.069	1.21±0.031
400	—————	1.21±0.047	1.21±0.113
800	—————	1.29±0.016	1.28±0.018

\*Average of three pots instead of four.

†Average of two pots instead of four.

‡Standard error.

With only one exception the percentage of nitrogen in the rye tops was increased due to the presence of the peas. The average increase was 0.41% which is very highly significant (Table 5). The nitrogen content of Austrian winter peas was increased 0.35% due to the presence of the rye. The increase in nitrogen content of Austrian winter peas due to the presence of rye has not been found in the literature with any legume.

#### EFFECT OF ASSOCIATION OF RYE AND AUSTRIAN WINTER PEAS AND OF NITRATE OF SODA ON TOTAL NITROGEN IN AUSTRIAN WINTER PEAS AND RYE

The data reported above show that the growth of rye and Austrian winter peas together reduced the yield of tops of both slightly and increased the percentage of nitrogen in both significantly. When the yield and nitrogen content are combined to give total nitrogen

(Tables 3 and 5), the Austrian winter peas grown alone and with rye contained considerably less nitrogen when the higher rates of nitrate of soda were applied. The total nitrogen in rye was increased with each increase in nitrate of soda applied.

TABLE 3.—*Effect of association of rye and Austrian winter peas and of nitrate of soda on the total nitrogen in Austrian winter peas and rye in grams per pot.*

Pounds NaNO <sub>3</sub> per acre	Austrian winter peas, grams	Rye, grams	Roots, grams	Total, grams
Austrian Winter Peas Grown Alone				
None	1.70±0.259‡	—	0.23±0.019	1.93±0.260§
50*	1.29±0.256	—	0.20±0.032	1.49±0.258
100	1.42±0.281	—	0.19±0.041	1.61±0.284
200	1.84±0.238	—	0.14±0.026	1.98±0.239
400†	1.28	—	0.10	1.38
800*	1.08±0.210	—	0.11±0.032	1.19±0.212
Austrian Winter Peas and Rye Grown Together				
None	1.55±0.026	0.15±0.016	0.36±0.057	2.06±0.065
50*	1.69±0.161	0.17±0.018	0.40±0.040	2.29±0.167
100	1.29±0.181	0.22±0.025	0.24±0.131	1.75±0.225
200*	1.57±0.055	0.23±0.004	0.33±0.038	2.15±0.067
400	1.13±0.255	0.38±0.041	0.25±0.035	1.76±0.261
800*	1.14±0.061	0.49±0.030	0.23±0.052	1.90±0.086
Rye Grown Alone				
None	—	0.12±0.006	0.06±0.000	0.18±0.006
50	—	0.14±0.005	0.10±0.000	0.24±0.005
100	—	0.18±0.011	0.09±0.000	0.27±0.011
200	—	0.24±0.011	0.10±0.018	0.34±0.021
400	—	0.37±0.005	0.13±0.012	0.50±0.013
800	—	0.65±0.032	0.13±0.023	0.78±0.041

\*Average of three pots instead of four.

†Average of two pots instead of four.

‡Standard error.

§The standard error of the total equals the square root of the sum of the squares of the standard errors of the figures added.

\*Standard error.

The growth of rye with Austrian winter peas tended to offset the reduction in total nitrogen produced by nitrate of soda on Austrian winter peas and, as a result, the total nitrogen in the peas and rye grown together did not vary as did that where the peas were grown alone. The total nitrogen was 1.66, 1.99, and 0.37 grams per pot where peas, peas and rye, and, rye, respectively, were grown (Table 5). The rye and peas had 0.33 gram of nitrogen more per pot than peas grown alone which is highly significant. The increased nitrogen in the peas and rye was practically equal to that in the rye grown alone.

The Austrian winter pea tops had practically the same total nitrogen when grown alone and when grown with rye even though the presence of the rye reduced the yield. Similarly, the lower yield of rye obtained in the presence of the peas contained about the same total nitrogen.

EFFECT OF ASSOCIATION OF RYE AND AUSTRIAN WINTER PEAS AND  
OF NITRATE OF SODA ON NITROGEN FIXATION

The percentage of nitrogen in each of three different samples of the soil at the beginning of the experiment was 0.0250 and that at the end of the experiment  $0.0260 \pm 0.00080$ ,  $0.0256 \pm 0.00072$ , and  $0.0255 \pm 0.00052$  (average of 22 determinations) where rye, Austrian winter peas, and Austrian winter peas and rye, respectively, were grown. On the basis of these data it is concluded that the crops had an insignificant influence upon the nitrogen content of the soil. The nitrogen fixed was obtained by subtracting the nitrogen added in nitrate of soda from that contained in the plants. The nitrogen in the seed was not taken into consideration. The Austrian winter pea and rye seed contained approximately 0.02 gram and 0.003 gram of nitrogen per pot, respectively. These data are reported in Tables 4 and 5.

TABLE 4.—*Effect of association of rye and Austrian winter peas and of nitrate of soda on nitrogen fixation in grams per pot.*

Nitrogen in plants, grams	Nitrogen added in $\text{NaNO}_3$ , grams	Nitrogen fixed, grams
Austrian Winter Peas Grown Alone		
$1.93 \pm 0.260^*$	0.00	1.93
$1.49 \pm 0.258^\dagger$	0.05	1.44
$1.61 \pm 0.284$	0.09	1.52
$1.98 \pm 0.239$	0.18	1.80
$1.38^\ddagger$	0.37	1.01
$1.19 \pm 0.212^\ddagger$	0.74	0.35
Austrian Winter Peas and Rye Grown Together		
$2.06 \pm 0.065$	0.00	2.06
$2.29 \pm 0.167^\ddagger$	0.05	2.24
$1.75 \pm 0.225$	0.09	1.66
$2.15 \pm 0.067^\ddagger$	0.18	1.97
$1.76 \pm 0.261$	0.37	1.39
$1.90 \pm 0.086^\ddagger$	0.74	1.16
Rye Grown Alone		
$0.18 \pm 0.006$	0.00	0.18
$0.24 \pm 0.005$	0.05	0.19
$0.27 \pm 0.011$	0.09	0.18
$0.34 \pm 0.021$	0.18	0.16
$0.50 \pm 0.013$	0.37	0.13
$0.78 \pm 0.041$	0.74	0.04

\*Standard error.

†Average of three pots instead of four.

‡Average of two pots instead of four.

The application\* of nitrate of soda in high amounts reduced the nitrogen fixed where Austrian winter peas, peas and rye, and rye were grown. The nitrogen fixed was 1.44, 1.77, and 0.15 grams per pot where Austrian winter peas, peas and rye, and rye were grown, respectively. The growth of rye with peas increased the nitrogen fixed 0.33 gram per pot which is highly significant.

The growth of rye with Austrian winter peas increased the nitrogen fixed in every case. Where 800 pounds of nitrate of soda were applied, the rye increased the nitrogen fixed from 0.35 to 1.16 grams per pot.

TABLE 5.—*Summary of the reciprocal effect of the association of rye with Austrian winter peas, average of 19 pots.*

Crop	Yield, grams per pot	Percent- age nitrogen	Total nitrogen, grams per pot	Nitrogen fixed, grams per pot
Whole Plants				
Austrian winter peas. . . . .	66.4	2.44	1.66	1.44
Austrian winter peas and rye. . . .	82.6	2.40	1.99	1.77
Rye. . . . .	36.2	0.94	0.37	0.15
Increase due to presence of rye. . .	16.2	-0.04	0.33	0.33
Odds (Student). . . . .	4999	2	232	249
Tops				
Austrian winter peas grown alone	59.0	2.39	1.43	—
Austrian winter peas grown with rye. . . . .	51.9	2.74	1.48	—
Increase due to rye. . . . .	-7.1	0.35	—	—
Odds (Student). . . . .	98	1393	—	—
Rye grown alone. . . . .	26.3	0.94	0.27	—
Rye grown with Austrian winter peas. . . . .	18.5	1.35	0.25	—
Increase due to presence of peas. .	-7.8	0.41	—	—
Odds (Student). . . . .	9999	9999	—	—

## SUMMARY

Austrian winter peas and rye were grown separately and together in the greenhouse in 3-gallon pots. Nitrate of soda was applied at the rates of 0, 50, 100, 200, 400, and 800 pounds per acre. The yield and nitrogen content of the tops and roots were determined. The following conclusions were drawn:

1. The application of nitrate of soda in large amounts reduced the yield and nitrogen content of Austrian winter peas when grown alone and when grown with rye.
2. The application of nitrate of soda increased the yield and nitrogen content of the rye in proportion to the amount of nitrate of soda applied.
3. The yield of Austrian winter pea tops was reduced slightly by the growth of rye with the peas.
4. The yield of rye grown with Austrian winter peas was almost as large as that of rye grown alone when small amounts of nitrate of soda were applied and considerably less when high amounts of nitrate of soda were applied.
5. The combined yield of Austrian winter peas and rye grown together was considerably greater than that of Austrian winter peas grown alone.
6. The percentage of nitrogen in the combined Austrian winter peas and rye grown together was not significantly less than that of Austrian winter peas grown alone.
7. The growth of rye with Austrian winter peas increased the average nitrogen content of the peas from 2.39 to 2.74%.
8. The growth of Austrian winter peas with rye increased the average nitrogen content of the rye from 0.94 to 1.35%.

9. The total nitrogen in the Austrian winter peas and rye was 0.33 gram per pot greater than where peas were grown alone.
10. The application of nitrate of soda reduced the nitrogen fixed where Austrian winter peas, Austrian winter peas and rye, and rye were grown.
11. The growth of rye with Austrian winter peas increased the nitrogen fixed from 1.44 grams per pot where peas were grown alone to 1.77 grams per pot where they were grown together.
12. The rye and the Austrian winter pea tops each contained practically the same quantity of nitrogen when grown together as each had when grown separately.
13. The growth of rye with Austrian winter peas increased the nitrogen fixed by an amount almost as large as the quantity of nitrogen in the rye, i. e., 0.33 and 0.37 gram per pot, respectively.

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## NOTES

### TWO IMPROVED NURSERY THRESHERS<sup>1</sup>

THE recent inclusion of light-seeded grasses and legumes in variety experiments at Pullman, Wash., has created a demand for better threshing equipment at this station. In an attempt to meet these needs a toothed-cylinder type of nursery thresher and a small roller-belt thresher have been constructed. The cylinder thresher is an improved model of one previously described.<sup>2</sup>

#### THE TOOTHED-CYLINDER THRESHER

The toothed-cylinder nursery thresher was designed to thresh a wide range of crop plants and to separate the seeds or fruits from the other plant parts rather completely or at least sufficiently to facilitate subsequent recleaning. A sketch of this machine is shown in Fig. 1, and photographs of the two sides are shown in Fig. 2. The principal features of the machine are as follows:

1. Over-shot cylinder, with hinged concave unit that is raised easily without stopping the machine, and which rises automatically when a foreign object gets caught in the cylinder accidentally, thus avoiding excessive damage to the teeth.
2. Beater with blades which practically stops the rebounding of grain out of the end of the short shaker, and which partly regulates the flow of material onto the shaker.
3. Short screenless shaker which carries the threshed material into the air stream.
4. Air blast cleaning system which usually cleans wheat, oats, peas, etc., sufficiently to permit the recording of yield weights without recleaning.
5. Sacking device to replace the grain pans for seeds that roll or slide easily.
6. Self-cleaning of internal parts.
7. Hinged feed board supported by a spring so as to be raised easily for cleaning.
8. Automatically controlled damper in feed chute to prevent seed from spitting back from the cylinder.
9. V-belts and assorted pulleys to permit the varying of the relative speeds of the cylinder and other moving parts.
10. Adjusting screws to level the machine on uneven floors (not used when the thresher is mounted on the trailer).
11. Recleaner attachment, consisting of a  $\frac{1}{4}$ -inch mesh screen-bottomed box and a fan to permit the recleaning of one sample while another is being threshed.

<sup>1</sup>Joint contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, the Division of Agronomy, State College of Washington, and the Pacific Northwest Soil Conservation Experiment Station. Published as Scientific Paper No. 385, College of Agriculture and Experiment Station, State College of Washington.

<sup>2</sup>VOGEL, O. A., and JOHNSON, ARTHUR. A new type nursery thresher. Jour. Amer. Soc. Agron., 26:629-630. 1934.

A  $1\frac{1}{2}$  h. p. air-cooled, self-oiled gasoline engine has proved to be a satisfactory source of power for most nursery samples.

For separating the stems from the fruits of alfalfa, red clover, and many grasses that have stems heavier than those of the fruits, a long-

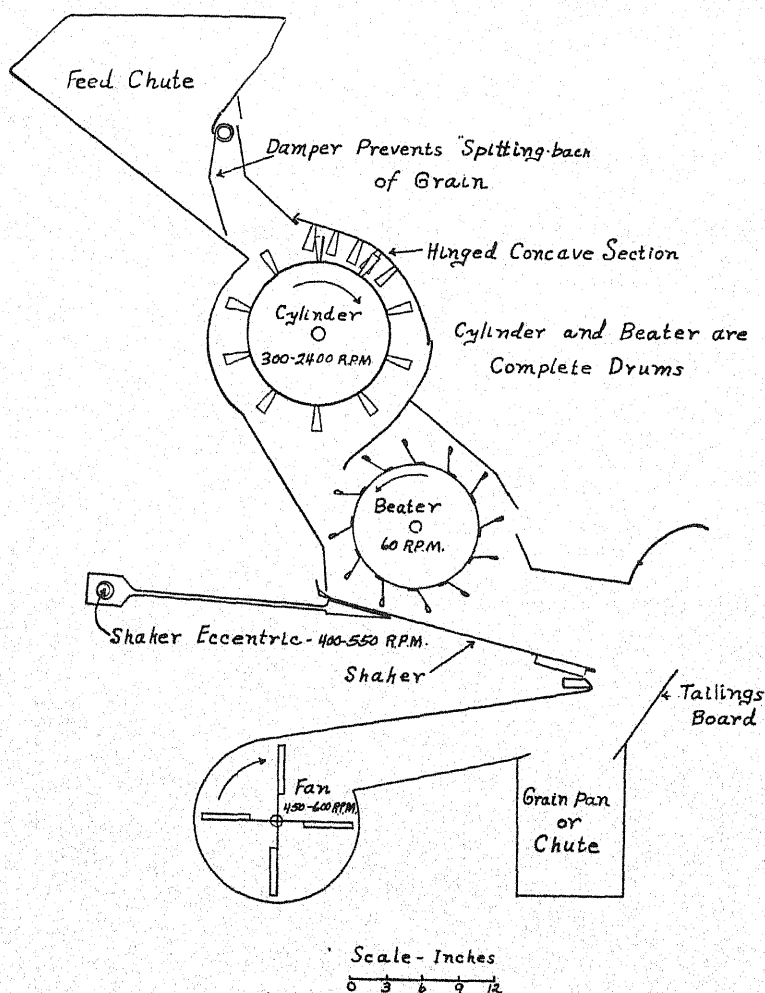


FIG. 1.—Working principle of the toothed-cylinder thresher.

toothed comb with  $\frac{1}{4}$ -inch spaces between the teeth is attached to the end of the shaker. This carries the stems over the end of the tailings board but allows the fruits to fall between the teeth into the pan. The comb functions satisfactorily because the stems are deposited on the shaker by the beater blades at right angles to the teeth of the comb.

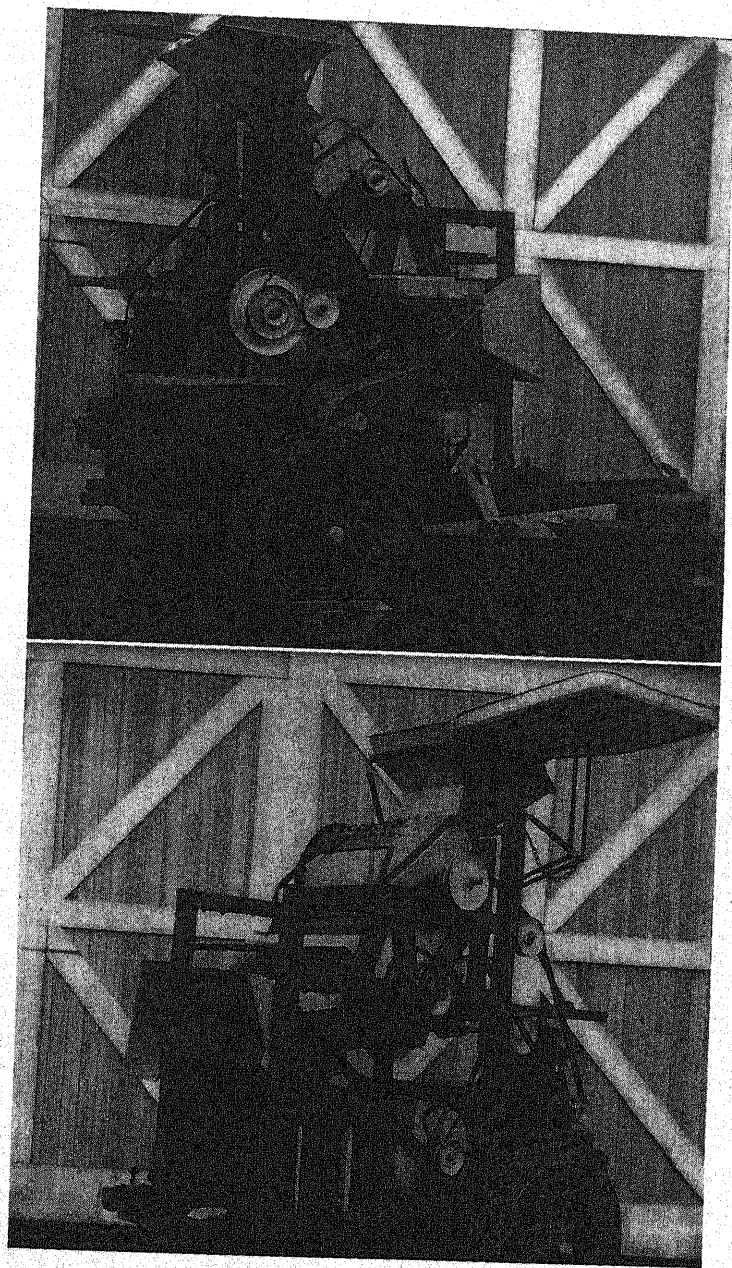


FIG. 2.—Two views of the toothed-cylinder thresher.

If so desired, a screen can be attached to the end of the shaker where it can be easily watched and cleaned.

The use of the thresher here described has reduced the cost of threshing and cleaning nursery samples of small grains during the past two years to a fraction of that required when inadequate equipment only was available. The thresher is towed to the nursery and set in a convenient location and the bundles, which are never wrapped, are carried to the thresher. The rate of threshing bundles containing 1 to 4 pounds of grain to be kept pure is approximately three to four per minute. Small bundles for pure seed containing not over 1 pound of grain, or larger bundles threshed only for yield, often are threshed at the rate of 300 to 325 per hour.

The entire bundle often is passed through the machine when the straw is less than 24 inches in length, but the butts of longer bundles usually are withdrawn. Bundles of small grain wrapped in paper and shipped to the station by cooperators are threshed without removing the paper as the latter does not interfere with threshing.

Samples of barley having some of the beards and hoods attached to the seed after threshing usually are set aside and rethreshed later with the cylinder speed reduced to avoid cracking the grain.

Sometimes a few partially threshed wheat heads remain in the threshed grain. These heads are later caught on the recleaner screen and are threshed quickly by rubbing them against the screen.

#### ROLLER-BELT THRESHER

The roller-belt thresher has been constructed so recently that it has not been tested so thoroughly as the toothed-cylinder thresher. It is designed primarily for small samples and is self-cleaning. As shown in Fig. 3, this machine operates on the very simple principle of a rough-surfaced roller rubbing against a slower moving rough-surfaced belt.

The belt, a 13-inch piece of hydraulic hose, 10 inches in diameter, and woven from 20-strand cotton cord, has a very rough surface. The wearing quality of the belt was increased by water-proofing with Lumino.

The three large rollers are made of wood and are 13 inches long and approximately 4 inches in diameter. A 13-inch piece of hydraulic hose, 4 inches in diameter and made of 20-strand cord, was slipped over the rubbing roller and fastened securely at the ends with sodium silicate (water glass). This hose was almost saturated with shellac to harden the fabric and increase its wearing quality.

A more wear-resisting corrugated or rough covering for the rubbing roller no doubt could be made of  $\frac{1}{8}$ -inch round steel welding rods placed side by side lengthwise of the roller and fastened to the surface of the wood cylinder with glue or sodium silicate. The rods should be welded or soldered together at the ends so as to render the resulting "cylinder" more able to withstand rough use.

The frame to which the two belt rollers are attached is suspended from the shaft of the upper roller, thereby leaving the lower end swinging freely. By moving the free end of the roller base toward the rubbing roller the pressure of the belt against the rubbing roller is

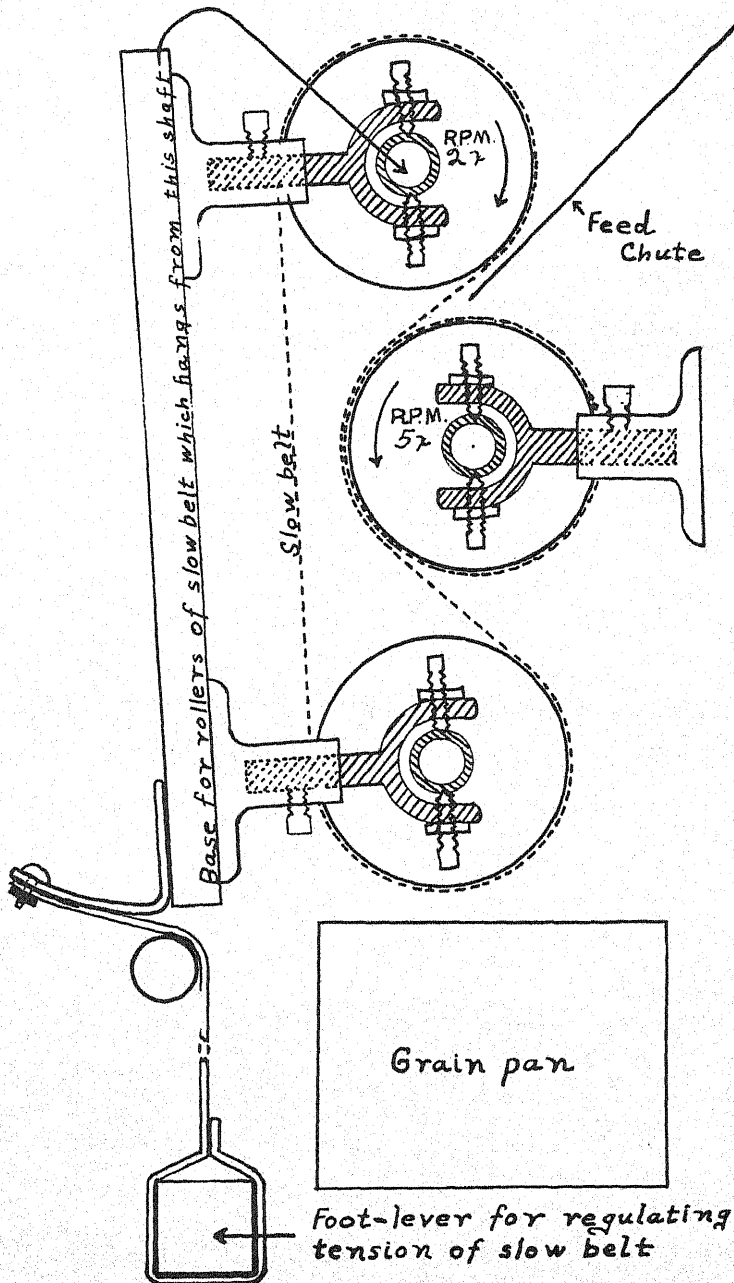


FIG. 3.—Working principle of the roller-belt thresher.

increased. This pressure is regulated at will by means of a foot-lever. The amount of rubbing surface is regulated by increasing or decreasing the distance between the belt rollers, thereby tightening or loosening the belt.

Photographs of two views of this thresher are shown in Fig. 4. The frame of one side of the machine was constructed so that in threshing the plant butts can be held to one side of the rollers to simplify the threshing and cleaning operations.

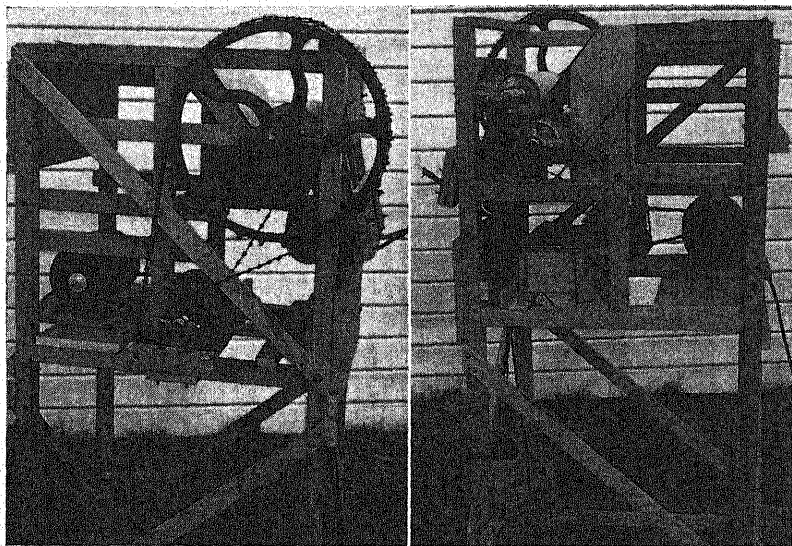


FIG. 4.—Two views of the roller-belt thresher.

A short roller was placed in a diagonal position between the two belt rollers to serve as a guide and to prevent the belt from traveling too far toward the sprocket side of the rollers.

Materials that have been threshed satisfactorily include heads and plants of wheat, oats, barley, flax, rice, sweet sorghum, and a number of grasses. The machine has been used to hull sweet clover, red clover, sainfoin, and alfalfa that was threshed with the toothed-cylinder thresher.

Large samples of alfalfa having too many pieces of hard stems were threshed more easily with another thresher consisting of a corrugated metal drum and an ordinary 12-mesh window screen which operates by a principle similar to that of the roller-belt thresher except that the screen is stationary but is easily removed for cleaning. A 16-mesh screen can be used for red clover with surprisingly good results. Either of these rubbing threshers can be run by a  $\frac{1}{3}$  h. p. electric motor.—O. A. VOGEL, *Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture*; WILFORD HERMANN, *Division of Agronomy, Washington Agricultural Experiment Station*; and LOY M. NAFFZIGER, *Pacific Northwest Soil Conservation Experiment Station, U. S. D. A., Pullman, Wash.*



**DETERMINING THE EFFECTIVENESS OF COMMERCIAL CULTURES  
OF NODULE-FORMING BACTERIA ON THE YIELD OF PINK  
BEANS (*Phaseolus vulgaris*), BLACKEYE BEANS (*Vigna sinensis*),  
AND WILBUR BEANS (*Phaseolus lunatus*)<sup>1</sup>**

THE gathering of nitrogen from the air in leguminous plants through the symbiotic relations between the host and bacteria (*Bacillus radicolica*) in nodules appearing on their roots has long been well established. It has been found that specific forms of these bacteria are necessary for nodule formation in each legume host. Several commercial preparations are found on the market to supply these specific forms where the legume host fails to form nodules, or even where the prevailing forms in a soil fail to give satisfactory performance. From time to time some of these commercial preparations of bacterial cultures have been tested in California. The behavior of three of these cultures is here reported.

In 1937 plats were sown at Davis with seed of pink beans (*Phaseolus vulgaris*), Blackeyes (*Vigna sinensis*), and Wilburs (*P. lunatus*). These beans represent the common varieties grown in California. Each was carefully inoculated with the specific bacterial culture designed for it, according to the directions accompanying the culture. The Wilbur and Blackeye beans were planted in double rows 300 feet long and spaced 30 inches apart, and the Pink beans on June 23 to avoid the effect of heat which causes blossoms of this variety to drop when planted earlier. The stands and set of seed were all satisfactory, without insect or disease damage of any sort. No difference in the appearance of the plants or seed could be detected when contrasted with the untreated similarly spaced checks which were in adjacent rows. At harvest yields were secured as reported in Table 1.

TABLE 1.—Yields in pounds of seed per acre of treated and untreated beans at Davis, Calif., 1937.

Variety	No. of plats	Check plats, pounds per acre	Treated plats, pounds per acre	Difference in yield, pounds per acre	Standard error, pounds per acre	Odds of significance*
Blackeye..	10	1,560	1,562	2	21	1.17:1
Wilbur....	10	1,875	1,888	13	49	1.86:1
Pink.....	20	1,161	1,228	67	58	6.61:1

\*Data analyzed by Student's method.

The differences in yield between treated and untreated checks for each variety of beans is shown not to be significant. Even for the Pink bean, which shows the most favorable yield, the increase in yield compared with the standard error is so small that for practical purposes it has no significance.

It must be concluded, therefore, that the Yolo silt loam at Davis, California, is well supplied with nodule-forming bacteria, fully as effective as those supplied by the commercial concern for the varieties of the three species of beans tested.

The Yolo series of soils includes the best and the most extensive bean soils in California and appears everywhere to possess an abundant flora of the necessary *Bacillus radicicola* for the beans under test. It has been found, however, that the specific forms required for causing nodules on garvanzo (*Cicer arietinum*) and on *Melilotus coerulea* have been absent in the years during which these legumes were under test.—W. W. MACKIE, *California Agricultural Experiment Station, Berkeley, California.*

## BOOK REVIEWS

### PLANT ECOLOGY

*By John E. Weaver and Frederic E. Clements. New York: McGraw-Hill Book Co., Inc. Ed. 2. XXII + 601. Pages, illus. 1938. \$5.*

THE second edition of this book which received so much favorable comment on its first appearance has been pretty completely revised in the light of the advances made in ecological work in the past decade. Evidence of the thoroughness may be noted in the bibliography which listed 601 entries in the first edition and which now contains 1,035 entries despite the fact that a considerable number of the older references have been dropped. This bibliography is an item of outstanding importance in this reviewer's opinion, and adds tremendously to an already extremely valuable book.

The text has been rewritten in many parts and has been reorganized in others. Over 60 pages of additional matter are incorporated into the text aside from the increased bibliography and index. Some of the illustrations have been replaced by better examples; a few have been added; and the location shown has been noted on the legends of a number which acquire more value from the added definiteness.

The chapter on Methods of Studying Vegetation has been enlarged considerably (16 pages) by addition of material on basal area, clip, frequency-abundance, and pantography-chart quadrats, isolation transects, relict method, pollen analysis, etc. The chapter on Units of Vegetation has been enlarged and further subdivided. These examples will illustrate the amount of revision. An effort has been made to emphasize the relation of ecological studies to conservation of natural resources.

To summarize briefly, the authors have included much recent data, corrected many of the weaknesses of the first edition, and have increased the value of the text very considerably. (G. P. VE.)

### REPORT OF THE FOURTH INTERNATIONAL GRASSLAND CONGRESS

*Edited by R. O. White. Aberystwyth, Wales: Imp. Bur. Plant Genetics. 486 pages. 1937. £2.*

THE volume is introduced with the presidential address by Professor R. G. Stapledon, pioneer pasture research worker, followed



with reports of business meetings and papers of members and friends of the Congress. The papers are divided into seven sections as follows: Plenary papers; grassland ecology, range management, and physiology; seed mixtures; plant breeding, genetics, and seed production; nutritive value of pastures and fodder conservation; pasture management and economics; and methods of obtaining yield determinations. Because of the large number of pasture research workers from many countries and varied climatic conditions, the reports are difficult to review.

This brief report on this volume of data is not indicative of its value to those interested in pasture research. The report should be widely accepted because grassland problems are disclosed from numerous scientific angles. Research workers should review these data.

A smaller volume with abstracts in English and German is available for five shillings, post free. (R. E. B.)

#### AN INTRODUCTION TO SOIL SCIENCE

*By Benjamin Isgur. Boston: Agricultural Scientific Publishing Co. 239 pages. 1938. \$2.50.*

THIS book is arranged primarily for students in a two-year course in agriculture. The subject matter discussed is not exhaustively portrayed, but rather the essential factors are related and much that is required to substantiate the subject matter left to the instructor's lectures. Only the relatively simple phenomena are taken up. The chapters noted are historical, some elements of chemistry, the origin of the earth, the rock-soil cycle, soil formations, soil separates and soil classification, soil texture and soil structure, tillage and tillage implements, soil surveys, plant nutrition and composition, organic matter and micro-organisms, soil acidity and lime, soil moisture, drainage and drainage systems, crop rotation, fertilizers, and soil diagnosis.

The book contains material serviceable for laboratory exercises. (W. S. E.)

#### AGRONOMIC AFFAIRS

##### METHODS OF APPLYING FERTILIZER

UNDER the above heading, the National Joint Committee on Fertilizer Application has published recommendations covering methods of fertilizing various crops as prepared by a special committee appointed at the thirteenth annual meeting of the Joint Committee in Chicago in November 1937. The recommendations were reviewed prior to publication by members of the Joint Committee and suggestions and corrections embodied in the published report.

The publication is a 16-page pamphlet with illustrations and includes a summary of recommendations for cotton, corn, tobacco, potatoes, snap beans, lima beans, peas, kale and salad greens, spinach, field beans, sweet potatoes, sugar beets, and small grains. A brief discussion of fertilizer distributing machinery is also included.

The report was published by the National Fertilizer Association and copies may be procured upon request to H. R. Smalley, General Secretary of the Joint Committee, 616 Investment Building, Washington, D. C.

#### NOTICE CONCERNING THE PROGRAM FOR THE 1938 MEETING OF THE CROPS SECTION

ALL members of the Society desiring to offer papers on the program of the Crops Section in Washington next fall are requested to communicate as soon as possible with the Chairman of the particular Sub-section in which the paper belongs, as indicated below. Dr. Ide P. Trotter, Chairman of the Crops Section, and other members of the Program Committee are desirous of completing the program by September 1. The Sub-sections and the Sub-section chairmen are as follows:

Sub-section I. Breeding, Genetics, and Cytology. Dr. R. J. Garber, Director, U. S. Regional Pasture Research Laboratory, State College, Pa.

Sub-section II. Physiology, including Nutrition, Morphology, and Taxonomy. Dr. F. D. Keim, Department of Agronomy, University of Nebraska, Lincoln, Nebr.

Sub-section III. Miscellaneous Crops Papers not Covered by Sub-sections I and II. Dr. Ide P. Trotter, Department of Agronomy, Texas A. & M. College, College Station, Texas.

Arrangements may also be made for conferences by small groups on special topics for inclusion in Sub-section III, but advance notice should be given the Program Committee as such conferences should be included in the printed program. If a meeting place for the conference is to be provided by the Committee, information to that effect should also be included in the notice to Dr. Trotter.

#### NEWS ITEMS

THE ANNUAL meeting of the Canadian Seed Growers Association was held at the Ontario Agricultural College at Guelph June 15 to 17:

THE IMPERIAL Bureau of Pastures and Forage Crops at Aberystwyth, Great Britain, has published as Bulletin No. 25 of its Herbage Publication Series a report on "Erosion and Soil Conservation". It includes a compilation of recent literature on soil conservation and gives attention to the degree and extent of erosion, the causes of erosion, and erosion control measures as practiced in the different parts of the world. The material is arranged according to countries and their political subdivisions, including the Mediterranean region, U.S.S.R., the East Indies, the West Indies, China, Japan, Africa, the United States, Canada, Australia, and Fiji.

DR. A. E. ALDOUS, Professor of Agronomy and specialist in pasture management of Kansas State Agricultural College, died suddenly on May 5 at the age of 51.

